SOAKING AND THERMAL PROCESSING EFFECTS ON BLACK BEAN QUALITY

BY

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"Try, I beseech thee, thy servants for ten days, and let pulse be given us to eat, and water to drink: And look upon our faces, and the faces of the children that eat of the king's meat: and as thou shalt see, deal with thy servants. And when he had heard these words, he tried them for ten days. And after ten days their faces appeared fairer and fatter than all the children that ate of the king's meat. So Malasar took their portions, and the wine that they should drink: and he gave them pulse." Daniel I, 12-16.

To Aricleusa

Consuelo and

Carla

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Soaking of black beans (Phaseolus vulgaris L.) prior to cooking and the subsequent effect on the quality and the kinetics of the cooking phenomenon were investigated. Texture was the main quality parameter studied and evaluated by sensory (multiple comparison tests) and instrumental (Instron puncture test) analyses. Distilled water, tap water, 0.5% sodium bicarbonate solution and a salt combination solution (2.5% sodium chloride, 1.0% sodium tripolyphosphate, 0.75% sodium bicarbonate and 0.25% sodium carbonate) were utilized as soaking media, and compared to unsoaked beans. The salt combination solution presented the slowest rate of water uptake at 10 °C, 22 °C and 35 °C, although the maximum water absorbed (around 95%) did not differ significantly among media. This solution, however, was the most effective in promoting bean softening upon cooking at both 100 °C and 121 °C. The texture of the cooked beans was relatively independent of the soaking time, amount of water absorbed and texture of soaked, uncooked beans. The salt combination solution required

only 1-hour soaking to produce adequately soft beans upon cooking. Black beans resisted overcooking without undesirable processing-induced softening. The salt combination solution produced the best results in the sensory evaluation for color, texture, flavor and overall acceptability. A high correlation ($r = 0.767$ at 100 °C and $r = 0.871$ at 121 °C) was found between sensory texture and puncture force. Log and power models were developed by regression analysis for predicting sensory scores based on instrumental data. Employing these models, an Instron puncture force equivalent to 150 g was used to define adequate cooking of black beans. This 150 g texture value was also used in kinetic studies of the cooking process. Cooking was carried out with unsoaked beans and beans soaked in distilled water and in the salt combination solution at temperatures of 90, 100, 110, 121 and 135 °C. Beans were packed in thermal death time cans and cooked in a water bath or a thermal death time retort. An iterative procedure was employed to estimate the thermal lag effect. Regression analyses were used to establish reaction rate (k), activation energy (E_a), D and z values for the softening process. Cooking of unsoaked beans produced E_a = 19,100 cal/mole, while water soaked beans reached E_a = 31,300 cal/mole and the salt combination solution was the highest, E_a = 38,900 cal/mole. The D_T values were defined as the cooking time at each temperature to produce a texture corresponding to 150 g puncture force. Based on these D_T values, z values were calculated as 36 C° for unsoaked beans, 21 C° for beans soaked in water and 17 C° for beans soaked in the salt combination solution. All z values were above the reported value for Clostridium botulinum (10 C°). However, some processing conditions which achieved

acceptable bean texture would require additional time in order to produce adequate Fo's. Kinetic data showed that the cooking mechanism is affected favorably by soaking prior to cooking. The kinetic relationships derived for black beans did not apply well for storage-abused black beans (5 months at 37 °C) or soybeans. Therefore, different bean types require distinct processing conditions. These are affected by species, variety, production parameters and storage history. The results of this investigation suggest that soaking should be used to shorten the cooking process for black beans, since the overall sensory quality is maintained. Furthermore, this procedure would provide more time and energy savings in both home and industrial preparations. The salt combination solution has excellent potential in the production of quick-cooking black beans.

INTRODUCTION

All foods are perishable commodities, with a gradual deterioration of plant and animal tissues beginning at the time of harvest or slaughter. This deteriorative process is caused by various biological forces—microbial activity, enzyme action and chemical reactions—which act under appropriate environmental conditions. The technology of food preservation is based on the control of these factors. Among the many preservation methods, heat processing has received the most research attention and is widely applied in the food industry. Besides stabilization, heat applied during cooking of certain food materials renders a more palatable food product. One of the most dramatic effects of heat on biological systems is protein denaturation, which produces inactivation of microorganisms and enzymes, and significant alteration of the chemical and physical properties of foodstuffs. Some heat labile nutrients, such as vitamins, and reactive amino acids are also reduced with an attendant decrease in nutritional quality. The desirable and undesirable effects of thermal processing depend upon the balance between the time-temperature relationships and the reaction kinetics of the food and environmental components involved.

The parameters for thermal processing of a specific product are established based primarily on microbial considerations. The thermal resistance of certain target microorganisms associated with heat penetration characteristics of the particular food provides the basis for

such thermal processing design. However, food safety from the microbial standpoint is so strongly emphasized that overprocessing frequently occurs. The results are reflected by both reduced nutritional level and organoleptic quality.

Dry beans, recognized as an important source of proteins, calories and other nutrients in many parts of the world, have unique characteristics concerning thermal processing. Unlike the majority of vegetables they require extensive cooking in order to rehydrate and tenderize the hard, dry beans to an edible softness and inactivate antinutritional factors. In the case of bean canning, cooking is accomplished during processing and is in excess of that required for sterilization.

Black beans (Phaseolus vulgaris L.) are the most common type of dry beans consumed in Latin America, including Brazil. They are cooked in approximately three times their weight of water. During the cooking process water is absorbed and thermal-induced softening occurs, until a desired texture is achieved. The typical black bean flavor is also developed during cooking. However, texture is more critical, since typical flavor is usually achieved before adequate texture is reached. In addition, flavoring agents are added before bean consumption. The final product has the appearance of a stew, with a thick broth containing the dark beans. It is important to note that the cooking process is quite long (about 2 hours at 100 °C), making it expensive in both energy and time. The use of simple procedures to decrease cooking time while maintaining black bean sensory quality would result in both increased energy and time savings.

The objectives of this study were to evaluate in detail the processing parameters of black beans necessary to achieve a desired quality level for consumption. The main points investigated were (a) the feasibility of using certain soaking regimes to decrease cooking time and their involvement in food quality, as evaluated by sensory and instrumental analysis; (b) the optimum parameters for processing of black beans regarding product quality; (c) mathematical models to predict sensory responses based on instrumental data; (d) kinetic parameters involved in the cooking process, and (e) the practical implications of the findings regarding canning and home preparation.

LITERATURE REVIEW

Legumes

The denomination legumes refers to the edible seeds of leguminous plants belonging to the Leguminosae family, one of the three largest families of flowering plants, involving nearly 700 genera and 18,000 species. The family comprises three sub-families, the largest of which, Papilionoidea, is widely distributed in both tropical and temperate regions. Its pea-like flowers grow from herbs and shrubs, and give rise to pods of several appearances, containing one or more seeds of varying size, shape, density and coat color (Purseglove, 1968). Each seed is attached to the pod at only one point, being easily detached. The seed is composed primarily of the seed coat and the cotyledon, the latter contributing 85% of the total seed composition. Legumes are dicotyledons, which store nutrients to feed the embryonic plant at the time of germination. No endosperm is present in legumes. The legumes used by humans are called food legumes or grain legumes. Pulse is a denomination given to the dried, edible seeds of food legumes. In legume processing, the term bean is used primarily referring to those of the Phaseolus genus (Siegel and Fawcett, 1976).

Legumes and Nutrition

Legume seeds represent a type of vegetable foods with a great potential as an underutilized protein source. They provide a large part

of the caloric and protein needs for most of the people in many parts of the world, such as Africa, India and Latin America (Aykroyd and Doughty, 1964; Siegel and Fawcett, 1976; Narasimha and Desikachar, 1978). Tables I and II show data on calories and protein supplied by cereal grains, food legumes and nuts in diets of developing countries, and protein consumption by major food groups, including pulses and nuts.

The importance of dry beans as human food derives from at least three major factors: their low cost, a relatively well balanced food value and ready acceptance in many cultures (LaBelle and Hackler, 1973). Legumes are responsible for 20 to 30% of the protein in the diet of Central America (Tandon et al., 1957; Bressani et al., 1963; Molina et al., 1975). Consumption in South America is also high. In Brazil, common beans, together with rice, form the staple diet of the majority of the population (Sgarbieri et al., 1978). Over 30 varieties of common beans are cultivated in Brazil, including many mixtures. This is due to market requirements, since consumer preferences vary according to geographical regions. Among all varieties, black beans present a large preference, mostly in Southern Brazil (Vieira, 1967; Medina, 1971). However, little attention has been given to common beans concerning their industrialization in that country (Gorgatti Netto and Rocha, 1971). The protein content of dry mature legume seeds, except soybeans and ground nuts, varies from 18 to 32% (Bressani, 1973). Variety and location highly influence protein content (Tandon et al., 1957).

Bressani et al. (1961) compared the composition in essential amino acids of six types of beans with the FAO pattern and concluded that methionine is the most limiting amino acid, leucine and tryptophane being

Table I. Calories and protein supplied by cereal grains, food legumes, and nuts in diets in the developing countries (% of total calories and proteins).

	Calories	Protein
Africa	58.5	61.3
Asia and Far East	72.1	77.3
Latin America	47.0	54.8
Near East	67.0	72.0
All developing countries	65.2	70.3

Source: FAO (1973).

Table II. Protein consumption (grams per day) per capita by major food groups.

	Cereals	Starchy roots	Pulses and nuts	Vegetables and fruit	Meat, eggs, fish, and milk	Total
North America	15.9	2.4	4.1	4.9	70.7	98.2
Central America	31.6	0.5	11.9	2.0	22.8	58.0
Caribbean	21.4	3.3	8.3	2.2	22.8	58.0
Africa	33.3	5.2	8.5	1.9	12.1	61.0
Near East	45.1	0.6	4.7	3.3	12.2	65.9
South Asia	32.3	0.5	8.6	0.6	6.3	48.3
China	31.8	2.9	10.8	2.2	8.8	56.5

Source: Abbott (1973).

second and third, respectively. Lysine content is high in dry beans, varying from 0.34 to 0.71 g/g N, but total sulphur amino acid content is low, from 0.03 to 0.11 g/g N, as well as tryptophan, reported as varying from 0.01 to 0.07 g/g N (Bressani, 1973).

Siegel and Fawcett (1975) stated that cereal proteins, relatively deficient in the essential amino acid lysine, can have their nutritional value markedly improved by the addition of synthetic lysine or of a food rich in lysine, such as legumes. This complementation has been evaluated for many vegetable mixtures, as polished rice and black beans (Bressani and Valiente, 1962), where the addition of limiting amino acids always showed a significant improvement in protein efficiency.

Antunes et al. (1979) nutrified dry brown beans by methionine infusion. The authors acclaimed this procedure to be important for use particularly in areas where the staple food including beans does not supply enough methionine to compensate for the deficiency of this amino acid in the seed proteins.

Antinutritional Factors in Legumes

Legumes contain natural substances that influence the nutritional value of these plant protein sources. These include protease inhibitors and hemagglutinins (the two most important), tannins, phytic acid and others (Rackis, 1974).

Protease inhibitors are proteic substances that have the ability to inhibit the proteolytic activity of certain digestive enzymes (Liener and Kakade, 1969). Trypsin inhibitor is the best known of these factors and was probably first detected by Read and Haas (1938). Kunitz (1945,

1946) isolated this compound in crystalline form. The realization that protease inhibitors might be of nutritional significance in plant foodstuff, mainly legumes, stimulated a search for similar factors in other plant materials. Several authors (Bowman, 1944; Borchers et al., 1947b; Jaffe, 1950a,b; Pusztai, 1966; Elias et al., 1979) reported the presence of such factors in plants of the Phaseolus vulgaris species, as navy beans, kidney beans, pinto beans and black beans. These factors have been found either in the cotyledons or in the seed coat (Liener and Kakade, 1969; Elias et al., 1979).

Most of the plant protease inhibitors are destroyed by heat application. The beneficial aspects of heat processing on the nutritional value of many varieties of P. vulgaris is well known. This relative ease to inactivate protease inhibitors by appropriate cooking has largely influenced the popularity of legumes as a staple component of the diet in many parts of the world. Most of the attention to effects and destruction of trypsin inhibitor has been devoted to soybean products. Borchers et al. (1947a) reported that the trypsin inhibitor activity of solvent extracted soybean meal was destroyed by exposure to flowing steam for 60 min or by autoclaving under the following conditions: 5 psi for 45 min, 10 psi for 30 min, 15 psi for 20 min and 20 psi for 10 min. Krishnamurthy et al. (1958) showed that soaking in water reduced the time required to inactivate trypsin inhibitor and improved the nutritive value of dehusked split soybeans ("dhal"). Germination and fermentation have also been indicated as decreasing trypsin inhibitor activity (Liener and Kakade, 1969; El-Hag et al., 1978). Kakade and Evans (1966), however, found no improvement of nutritional value of navy beans upon

germination, although some decrease in trypsin inhibitor activity was observed during the first 2 days of germination.

Hemagglutinins (or phytohemagglutinins or lectins) are proteins that are able to agglutinate red blood cells. They are found in many parts of plants and have been more frequently detected in plants from the families Leguminosae and Euphorbiaceae (Jaffe, 1969). The first reference to these compounds dates back to the work of Stillmark in 1889 (cited by Jaffe, 1969) in studies with castor beans. All phytohemagglutinins show differences with respect to their activity on blood of different animals, and have been classified as "specific" and "non-specific" agglutinins, according to their activity toward different human blood groups. Ten phytohemagglutinins have been described as originating from the families Leguminosae and Euphorbiaceae (Jaffe, 1969). Jaffe and Gaede (1959) studied a purified toxic phytohemagglutinin from black beans, called Phaseolotoxin A.

Like other growth inhibiting factors, hemagglutinins are also heat labile. Autoclaving of soaked kidney beans provided complete elimination of the toxicity (Jaffe, 1949). No hemagglutinin activity was found in black beans cooked 20 min at 121 °C (Elias et al., 1979). Kakade and Evans (1965) found that autoclaving for 5 min was sufficient to eliminate the toxicity of finely ground navy beans meal. However, 30 min of dry heating had little effect on hemagglutinin activity of certain varieties of P. vulgaris, and activity was still detectable after 18 hours of treatment (de Muelenaere, 1964).

Elias et al. (1979) suggested that the pigments present in the seed coat of beans, including black-coated beans, contain high levels of heat

resistant tannins and other related polyphenols that inhibit trypsin activity. These compounds can react with proteins, decreasing their digestibility and, therefore, their quality.

Cooking and Nutritive Value of Beans

During preparation of dry beans for eating, they are rehydrated and cooked, in the same operation or separately. Rehydration is the physical absorption of water, whereas cooking involves physical and chemical changes such as the destruction of toxic factors, gelation of starch and denaturation of protein (Burr, 1973). Several researchers (Kakade and Evans, 1965; Gomez Brenes et al., 1973; Molina et al., 1975) have shown the deleterious effect of excessive heat on the nutritive value of beans. It is widely recognized that considerable losses of some of the water-soluble vitamins can occur during the pre-soaking step, or this loss can occur if the liquid in which the beans have been cooked is not consumed. It has been reported that as much as 50% of thiamin can be lost during canning (Miller et al., 1973). Significant amounts of pyridoxin, niacin and folacin have been found in the liquid medium surrounding the beans during soaking and cooking steps. The beneficial effects of heat processing on eliminating some of the antinutritional factors is overshadowed by the concurrent losses of protein quality in the canned beans. Gomez Brenes et al. (1973) reported an increase in protein efficiency rate (PER) of black beans, from zero (raw beans) to 1.24 (cooked beans), due to the destruction of antinutritional and toxic factors. However, cooking at 121 °C beyond 30 minutes resulted in a decrease in PER and in the available lysine as cooking time increased. The results are shown in Table III.

Table III. Effect of cooking time at 121 °C on the protein quality of beans.

Cooking Time (min)	Protein Efficiency Ratio	Available Lysine g/16 g N
0	0*	7.96
10	1.31	6.13
20	1.35	5.10
30	1.29	5.79
40	1.20	6.28

Source: Gomez Brenes et al. (1973).

* All animals died.

Castro (1976) studied the effects of processing variables on available lysine content of black beans. Available lysine content was found not to be affected by cooking at 100 °C and 121 °C, after soaking in several media. However, Datta and Datta (1978), studying cooking of "dhals" (split pulses) of five legumes (Lens esculenta, Phaseolus mungo, Lathyrus sativus, Cicer arietinum and Pisum sativum), verified that the available lysine was higher in samples cooked without a pressure cooker for 30 minutes than those cooked 10 minutes in a pressure cooker.

Factors Affecting Cooking Procedures

Dry beans require a relatively severe heat treatment (cooking) in order to produce an edible product. Tenderness, flavor and color are the main quality attributes enhanced by heat processing. Different degrees of heating are required to cook the beans, depending on the manner of consumption. They can be consumed as whole-cooked, whole-fried or strained and fried (Gomez Brenes et al., 1973).

Mattson (1946) explained the softening of peas during cooking as occurring through a reaction of phytate (present as Na/K phytate) in the cotyledons, with the insoluble Ca/Mg pectate present in the cell wall (especially those of the seed coat), which converts the Ca/Mg pectate to the soluble Na/K pectate. Smithies (1960) reported a good correlation, at low average phytic acid content, between the cooking quality of dry peas and their phytic acid content. Muller (1967) studied the effects of free pectin, phytic acid, calcium and magnesium on the cooking quality of pulses. Sodium citrate was used in a soaking solution as calcium and magnesium fixer, resulting in softening of the bean texture.

Cooked beans are known to differ in degree of tenderness. Theophrastus (1916) classified dry beans as "cookables" and "uncookables." During immersion in water, some of the individual beans do not imbibe water, which is attributed to the impermeability of the seed coat. This condition is called "hardshell" (Gloyer, 1921), and has been associated with low moisture and high temperature storage (Gloyer, 1932; Burr et al., 1968; Burr, 1973). According to Bourne (1967), hardshell beans tend to be smaller than normal ones. This size disparity is increased by soaking, so the smaller seeds can be eliminated by size grading after soaking.

The increase in required cooking time has been related to time, temperature, moisture content and relative humidity during storage. Morris and Wood (1956) adjusted samples of seven varieties of beans (Phaseolus vulgaris and P. lunatus) to different moisture levels and stored them at 25 °C. Samples were periodically taken, cooked and given to a sensory panel. After 6 months of storage at 13% moisture or higher, beans showed significantly firmer texture than those stored at lower moisture. Morris (1964) also verified that both low moisture and reduced temperature of storage are more beneficial to the ease of cooking beans.

Muneta (1964) reported differences in cookability of the same varieties of beans grown at different locations, as associated with the moisture level. Rockland and Metzler (1967) found that their quick-cooking Lima beans, prepared by infiltration of various salt solutions into the beans and further redrying, also took longer to cook after storage at elevated temperature.

Sefa-Dedeh et al. (1979), working with Ghanainan cowpeas, found that the rate of cooking of the beans decreased with increasing storage

temperature and that storage at 29 °C induced the formation of the "hard-to-cook" defect. The microstructure of the defective beans showed an incomplete breakdown of the middle lamella which may partially explain this hardness defect.

Kon (1968) studied the pectic substances in dry beans and their possible correlation with cooking time. Two lots of beans were stored at 90 °F (approximately 32 °C) for 4 years. The low moisture beans (8.5%) required 39 minutes to cook, while the high moisture sample (13.3%) was cooked only after 210 minutes. Heat treatment was credited with converting some of the water insoluble pectin to water soluble. However, no significant difference was found between pectic substances extracted from the low and high moisture beans.

Rockland and Metzler (1967) stated that legume proteins may influence the texture and cooking of cotyledons. McKee et al. (1955) pointed out that the formation and aggregation of protein were a consequence of the final stages of maturation and dessication of peas. So, fresh beans and peas cook more rapidly than more mature ones. Molina et al. (1976) showed the content of lignified protein in the cotyledons to be highly correlated with the hardness value in cooked black beans.

Narasimha and Desikachar (1978) reported that cooking tests on "pearls" (dehusked grains without splitting) prepared from ten varieties of "tur" (Cajanus cajan) indicated high correlation between cooking time and the content of calcium, magnesium, pectin and phytin, and the PMCP (free pectin + calcium + 1/2 magnesium - phytin) number.

Ganesh Kumar et al. (1978) studied the cooking characteristics of some germinated legumes. They suggested that the affinity of Ca^{++} and

Mg^{++} ions to phytic acid play a primary role in affecting the cookability of legumes. During cooking, calcium migrates into the cell, complexing with phytate ions. Further, the permeability of the cell wall is altered by the presence of Ca^{++} and Mg^{++} ions. More soluble calcium salts might be formed during these changes, which get leached out. The change in pH, degree of hydration, stability of the complex salts and the cell wall uronic acids may also interfere in the cooking process.

Recently, Lai and Varriano-Marston (1979) studied the physicochemical properties of black bean starch. The isolated starch had a high amylose content and showed restricted swelling and solubility patterns when cooked in excess water. They suggested that these characteristics contributed, in part, to the limited starch swelling observed in situ in cooked beans. The physical and chemical barriers imposed by cell walls and intracellular material were indicated as limiting factors in starch swelling. No clarification was obtained on the role of starch in the cooking quality of black beans. It appears unlikely that significant amounts of amylose would diffuse through the cell wall to appreciably increase intercellular adhesion during the cooking of black beans.

Pre-Soaking of Beans

Soaking in Water

As an aid in the cooking step, pre-soaking of beans has been routinely recommended for home and commercial operations (Aykroyd and Doughty, 1964; Steinkraus et al., 1964; Adams and Bedford, 1973; Parpia, 1973; Barkker et al., 1973; Dutra de Oliveira, 1973; LaBelle and Hackler, 1973). The practice has several purposes: to ensure product tenderness

and uniform expansion in the can during the thermal process, to increase product yield and to facilitate cleaning of the beans (Hoff and Nelson, 1966). Also removal of toxic substances has been associated with soaking (Bressani, 1973; Dutra de Oliveira, 1973).

In commercial operations, dry beans are usually hydrated for 12-16 hours prior to cooking (Campbell, 1950).

The seed coat has been shown by Smith and Nash (1961) to be the principal factor controlling the rate of water uptake. Hamad and Powers (1965) reported an inverse relationship between the rate of water imbibition and the pectic content of dry beans, particularly the water-soluble pectin. Water uptake varies according to the pH of the soaking solution, being slower in weak acid solutions (Snyder, 1936; Powers et al., 1961). Quast and Da Silva (1977b) studied the hydration rate of dry beans as influenced by temperature. A maximum moisture content (120 g H_2O/100 g dry beans) was reached in black beans at temperatures above room temperature (23 °C), being faster at higher temperatures (30 and 40 °C).

Kon (1979) studied the effects of soaking temperature on cooking and nutritional quality of white beans. Best results were obtained with beans soaked in water at 90 °C. However, under those conditions, some nutrients are lost and the total nutritional value of the beans might also be affected due to the possible effect on the availability of starch.

Hoff and Nelson (1966) compared vacuum, steam pressure and sonication treatments to degas beans prior to soaking, in order to improve water uptake. They suggested that gases—probably nitrogen, oxygen and carbon dioxide—fill the intersticial pores and are adsorbed on the

internal surfaces of both seed coat and cotyledons, thus preventing water from migrating into the tissues. It therefore seemed reasonable to assume that water uptake would be enhanced if these gases could be released from the beans, thus allowing more water to enter the pores more rapidly. All treatments accelerated water uptake within the first 20 minutes of soaking. However, at 80 °C effects of the treatments were very similar, but at room temperature water uptake was appreciably different among treatments, with sonication presenting higher values than steam pressure and vacuum. Maximal uptakes occurred when soaking was done in the 60-80 °C range. Sefa-Dedeh et al. (1978) reported that soaking in water at 25 °C prior to cooking produced a softer texture in cowpeas, and the decrease in hardness was proportional to the soaking time.

Soaking with Chemical Solutions

Chemical solutions, such as sodium bicarbonate (up to 0.5%) for navy beans (Ferrier and Rosborough, 1975), have been used to improve softening of dry beans upon cooking. Quast and Da Silva (1977b), however, reported that a 0.3% sodium bicarbonate solution had no effect on the hydration time of dry beans, compared to tap water, while a surfactant, Tween 80, increased the required soaking time for black beans.

Quick cooking dried beans were produced by Bjorkquist et al. (1972) by means of soaking in a solution containing sodium carbonate, citrate or tripolyphosphate, for approximately one day.

More sophisticated soaking solutions of inorganic salts have been used by Rockland and Metzler (1967). They utilized solutions of

inorganic salts to disperse or solubilize proteinaceous material. The addition of chelating agents, such as phosphates, was intended to aid in dissociating possible calcium and other metal salt-protein complexes. Except for these points, the development of a suitable hydration medium was carried out empirically. The most generally useful medium contained as ingredients: sodium chloride (2.5%), sodium tripolyphosphate (1.0%), sodium bicarbonate (0.75%) and sodium carbonate (0.25%). This formulation was effective, although not necessarily optimum, for all the dry beans studied. Other chemical agents presented either no advantage, as other phosphates, or were more expensive, as ethylenediaminotetraacetate (EDTA).

Rockland et al. (1979) produced quick-cooking winged beans using the same formulation above. The product tenderized in boiling water within 20 minutes or at about 10% of the time required to cook untreated, water pre-soaked beans. The cooked, quick-cooking beans presented a smooth uniform texture, excellent whole bean appearance and enhanced natural flavor.

Rockland et al. (1977) observed the content and retention of thiamin, pyridoxin, niacin and folacin in quick cooking beans (large Lima, pink, pinto, blackeye) prepared with the same salt combination. Cooked, quick-cooking Lima and blackeye beans had slightly higher levels of all four vitamins than standard cooked beans, but standard cooked pink and pinto beans had higher levels of thiamin, pyridoxin and niacin; folacin results were inconsistent. There was no consistent relationship between vitamin content and cooking time.

Varriano-Marston and De Omana (1979) studied the effect of the formulation used by Rockland and Metzler (1967), except for the amount

of sodium chloride (1%), on the chemical composition and morphology of black beans. Tap water, deionized water and solutions of sodium chloride (1%), sodium tripolyphosphate (1%), sodium bicarbonate (0.75%) and sodium carbonate (0.25%) were also checked for their effect. They reported that the amount of sodium did not affect the amount of water absorbed by the beans, pH being the critical determinant. More water absorption was obtained in solutions with the most alkaline initial pH. However, the sodium salts affected the mineral content as well as the amount of pectic substances solubilized from the beans during soaking and cooking regimes. X-ray microanalysis suggested that mechanisms of ion exchange and chelation were operative in the dissolution of the intercellular cement and the subsequent cell separation, rendering "quick-cooking" beans.

Ankra and Dovlo (1978), pursuing a traditional Ghanainan soaking procedure, used "trona" —a hydrated, basic sodium carbonate containing $Na_2CO_3.NaHCO_3.2H_2O$, with a mean value of 25% sodium, small amounts of potassium and calcium, and traces of iron and magnesium—in the cooking water of cowpeas. The reduction in cooking time with 0.5 g of trona per 25 g of cowpeas ranged from 20 to 35 min. However, a mixture of 2 g of trona per 100 g of cowpeas produced discoloration and off-flavor.

Narasimha and Desikachar (1978) used sodium bicarbonate, trisodium phosphate and ammonium carbonate solutions as aids in reducing the cooking time of Red gram dahl. The most effective treatment was achieved by coating and drying the dahl prior to cooking. Addition of the chemicals to the cooking water resulted in an alkaline taste. A reduction of about 50% in cooking time could be achieved with the use of either coating or pre-soaking with the studied salt solutions.

Mixed treatments have also been studied. Luh et al. (1975) recommended the treatment of hardshell dry baby Lima beans with pre-heating in boiling sodium hydroxide solution (1.0%) for 2-3 minutes, followed by soaking in tap water for 12 hours at room temperature. Castro (1976) also applied boiling solutions of sodium hydroxide (0.1%, 0.2% and 0.3%) for two minutes, in treating black beans prior to soaking four hours at room temperature. It was concluded that sodium hydroxide solutions soften the beans, but the effect on the bean appearance may limit their use to treatment of hardshell beans.

Texture Measurement of Beans

Instrumental Texture

Texture is probably the most important characteristic of cooked beans. Beans cannot be consumed in the dry or simply rehydrated states; cooking is used to impart an adequate degree of softness for eating purposes.

Instrumental techniques for measuring bean texture have been used for different purposes, such as estimating the quality of processed Lima beans (Kramer and Mahoney, 1940), maturity of fresh Lima beans (Salunkhe and Pollard, 1955), cooking rates of Lima beans (Binder and Rockland, 1964), and changes in toughness of green snap beans as affected by growing temperatures (Dunlop and Ormrod, 1970).

Burr et al. (1968) used an ingenious puncture test to determine the cooking time and effects of various storage conditions on the cooking rate of dry pinto, Sanilac and Lima beans. They mounted 100 metal punches, each weighing 90 g, over 100 beans. The beans held in small

metal cups had been soaked in tap water at room temperature for 18 hours. The lower portion of the apparatus was immersed in boiling water. By recording the number of beans penetrated by the plungers at certain time intervals, they established the cooking time of the beans as that required to puncture 50% of the beans.

Utilizing a similar apparatus, Michiels (1973) developed a method to assess optimum cooking time and temperature of canned dry beans. A series of isothermal lines was constructed on a graph, relating the logarithm of the percent of beans not penetrated by the plungers and the cooking times. D and z values were obtained from this plot. Through the use of graphic relationships, the author determined that a suitable texture was achieved when the percent of beans resistent to complete penetration reached between 2 and 10%.

The texture of canned baked beans was studied by Voisey and Larmond (1971), using the tenderometer, shear press and several extrusion cells. A high degree of intercorrelation between the different instrumental measurements was found, and between objective and sensory methods as well. They stated that the selection of a texture analysis method can be based on practical and economical considerations.

Bourne (1972) has adapted the Instron Universal Testing Machine for use in measuring individual texture of cooked beans. The method was indicated as suitable for determining how variable single units are. With instruments that measure several beans at the same time, an average effect is obtained. A shortcoming, however, is the inability to detect outstandingly hard beans, which can cause problems when chewed.

Quast and Da Silva (1977a) studied the texture of cooked beans with the use of a Kramer shear press. The highest correlation with cooking time was represented by the maximum shear force, expressed in lbf/g. Sefa-Dedeh et al. (1978) developed a wedge texture test cell to provide information about the texture of raw and soaked cowpeas. These data were correlated to the texture of the cooked product through multiple regression equations that showed a good prediction of the cooked bean texture.

Sensory Texture Evaluation and Correlation with Instrumental Measurements

The use of sensory evaluation of texture is also extremely valuable. No instrument can perceive, analyze, integrate and interpret a large number of textural sensations at the same time. Even if the human mouth could be duplicated in an instrument, we would still have to duplicate the nervous system which has the important function of receiving and translating the signals from the receptors in the mouth. The pleasure center in the brain plays a very important role in the sensory evaluation. Even with strictly trained panels, which attempt to be as analytical and objective as possible, sensory evaluation often gives important information on psychological reaction to the product (Larmond, 1976).

Adams and Bedford (1973) stated that the texture of beans can be evaluated with reasonable accuracy by a sensory panel, and also can be measured quantitatively by machines with proper recording systems and test cells. Their initial studies showed that consistent results can be obtained when the beans are washed with tap water to remove sauce, and instrumental measurements are made at a selected, constant temperature. The results showed a high degree of correlation ($r \geq 0.95$) between objective and sensory evaluations for texture.

Castro (1976) investigated interrelations of soaking solutions, soaking and cooking time and cooking temperatures on the texture of black beans. The texture was measured in a Instron Universal Testing Machine using wire extrusion cell and by sensory panel. All treatments (0.5% sodium bicarbonate, 1% citrate, 01-0.2-0.3% hot sodium hydroxide pre-treatment)yielded softer cooked beans as measured instrumentally and by sensory panels. Soaking and cooking regimes did not show any adverse effects on the flavor of the beans. Pre-soaking and subsequent cooking at 121 °C were shown to shorten cooking time of black beans, compared to unsoaked beans, while maintaining the acceptability.

The use of a rating scale enables the researcher to simultaneously measure the physical properties of a food and allows the panelists to sensorially assess the same food in a quantitative way. Analysis of the data obtained can be performed by computing correlations between the instrumental and the sensory measures. If an equation can be found to describe the relationship, it can tell the researcher what is the likely sensory response to known changes in the physical product, quantified by instrumental measures. A regression analysis is used to relate statistically the sensory measure to one or more physical measures (Moskowitz, 1977).

Soo and Sander (1977) developed a method for the objective measurement of textural parameters of fabricated comminuted shrimp-binding matrix agent mixtures using the Instron. A texture profile analysis of fabricated cooked shrimp patties was used to predict sensory textural scores on subsequently mechanically extruded shrimp shapes through regression analysis equations. The technique eliminated expensive and

time consuming pilot plant operation of equipment to produce a sufficient quantity of the product for analysis.

The power function $S = k I^n$, proposed by Stevens (1960), in many cases appears to be adequate in relating sensory (S) and instrumental (I) measurements of texture. Moskowitz (1972) and Moskowitz et al. (1974) used this relationship to develop values of n, which is a measure of how rapidly the values of the subjective score change with increasing values of the physical intensity.

Thermal Processing of Foods

Uses of Thermal Processing

Thermal processes are important methods for extending the utilization of foods through extension of their storage life. Actually, the term "thermal process" can be applied to any process in which heat energy is transferred to (such as in canning and dehydration) or from (such as in refrigeration and freezing) the food. However, in this review, thermal processing will relate only to application of heat to food products.

Thermal processes, as defined by Lund (1977), may involve blanching, pasteurization and commercial sterilization. Blanching, at around and below 100 °C, is frequently applied to tissue systems prior to freezing, drying or canning, with the objectives of activating or inactivating enzymes, facilitating packing, removing gases from plant tissues, increasing product temperature. Pasteurization, also below 100 °C, is intended to inactivate most of the vegetative microbial flora present in the food. Usually other preservation techniques follow pasteurization to ensure product stability (e.g., refrigeration, additives). Commercial

sterilization, above 100 °C, is usually designed to inactivate microorganisms or their spores, which would grow and produce spoilage or health hazards under the conditions of storage.

The decision to apply a more or less drastic process for preservation is primarily related to the acidity level of the food under question. Foods have been classified as "acid" and "low-acid," the dividing line being established as the pH 4.6. Acid foods, as most fruits, present a pH below 4.6 and are adequately processed at temperatures around 100 °C. Low-acid foods, as the majority of the vegetables, are defined as any commercially processed food with a finished equilibrium pH value greater than 4.6 and a water activity greater than 0.85. These food products require drastic processing conditions, usually at 10 psi (115 °C) or 15 psi (121.1 °C) (NCA, 1973).

The main concern in processing of low-acid foods is Clostridium botulinum spore survival, which is able to germinate and produce a deadly toxin under favorable conditions. However, most processes are based on the inactivation of more heat resistant spores than those of Cl. botulinum. Putrefactive anaerobe (PA) 3679 is used in studies of process adequacy, due to its high heat resistance, ease of assay and non-toxicity (NCA, 1976).

Kinetics of Thermal Processing

The thermal destruction rate of microorganisms, enzymes and many food components (color, texture, flavor, nutrients) generally follows first-order reaction kinetics. It is dependent on the concentration of the component and the relationship is known as "logarithmic order of

inactivation or destruction," due to the constant rate of reaction per unit time regardless of the initial concentration (Lund, 1975).

In the case of microorganisms, the mathematical first-order response can be expressed as (Ball and Olson, 1957; Stumbo, 1973; Merson et al., 1978):

$$\frac{-dc}{dt} = kc$$

where: $-dc/dt$ = rate of decrease in concentration

c = initial concentration of microorganisms

k = first order reaction rate constant

The integration of this expression between the limits c_1 at time $t_1 = 0$ and c at time t gives:

$$-\int_{c_1}^{c} \frac{dc}{c} = k \int_{t_1}^{t} dt$$

$$-\ln c + \ln c_1 = K (t-t_1)$$

$$\log c = \log c_1 - \frac{kt}{2.303}$$

This relationship can be graphically expressed as shown in Fig. 1. From this curve, it can be seen that one log cycle corresponds to a reduction of 90% in the number of microorganisms. The time required to cause this reduction is called "decimal reduction time" or D value and expressed by (Ball and Olson, 1957; Stumbo, 1973):

$$\frac{-\log c_1 - \log c}{D} = \frac{-\log (c_1/c)}{D} = \frac{-\log (100/10)}{D} = \frac{-1}{D}$$

The slope is $-k/2.303$, then:

$$\frac{-k}{2.303} = \frac{-1}{D}$$

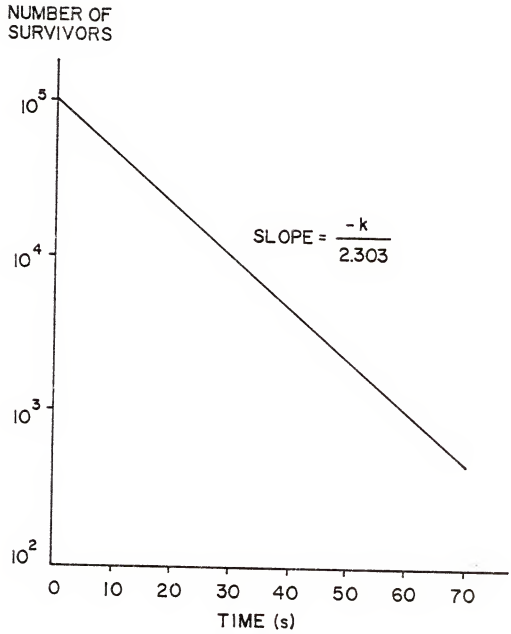


Fig. 1. First-order destruction of microorganims at 121° C (from Lund, 1975).

and $D = \frac{2.303}{k}$

Reaction Kinetics and Temperature

Each survivor curve is defined for each particular microorganism in a defined environment and constant temperature. In food processing, heating of the food is not instantaneous, so that a range of temperatures is obtained before reaching processing temperature. So, it is necessary to account for the effect of each lethal temperature. Different temperatures, obviously, have different lethal effects and they can be compared if the dependence of reaction rate on temperature is established. The Arrhenius equation expresses this dependence as (Lund, 1975):

$$k = s^{(E_a/RT)}$$

where: k = reaction rate constant (min^{-1})

s = frequency factor, constant (min^{-1})

E_a = activation energy (cal/mole)

R = gas constant (1.987 cal/Kmole)

T = absolute temperature (°K)

Another way to express the dependence is through the semi-log plot of thermal death time (TDT)—minimum time to accomplish total destruction—against temperature. This results in a straight line (Bigelow, 1921), as illustrated in Fig. 2.

The curve can be described as:

$$\log \frac{TDT_1}{TDT_2} = \frac{-1}{z} (T_1 - T_2) = \frac{T_2 - T_1}{z}$$

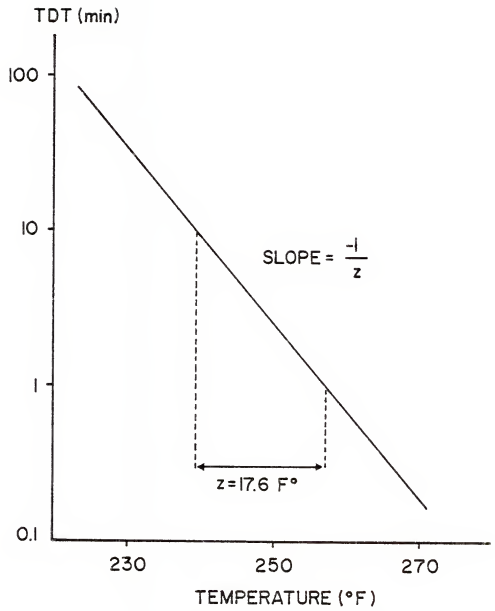


Fig. 2. Thermal death time (TDT) curve for Clostridium botulinum in phosphate buffer (from Esty and Meyer, 1922).

Where: TDT_1 = TDT at T_1 (min)

TDT_2 = TDT at T_2 (min)

T_1 = temperature 1 (°C)

T_2 = temperature 2 (°C)

z = temperature change (C°) required to change the TDT by a factor of 10

The slope of a TDT curve, -1/z, characterizes the dependence of the reaction on temperature. The use of the z value is very meaningful to illustrate this dependence. Ball (1923) stated that "z represents the slope of the curve, its value being the number of degrees passed over by the curve in traversing one logarithmic cycle." The smaller the z value, the higher the temperature dependence of the studied parameter.

It is common to use the symbol F to represent the thermal death time for microbial inactivation, which is generally given by 12 D or 12 log cycle reduction in number of survivors. A thermal process is usually represented as

$$F_{250}^{18} \quad \text{or} \quad F_{121}^{10}$$

which means the TDT at 250 °F (or 121 °C) to destroy a microorganism with z = 18 F° (or 10 C°). The notation Fo expresses the sterilizing value of a process at 121 °C (250 °F). This term is useful to compare the effect of different processing times and temperatures in relation to 121 °C.

Values for different temperatures can be derived from the reference temperature by the equation (Bigelow, 1921; Stumbo, 1973; Pflug and Odlaug, 1978):

$$\log \frac{F_T^z}{F_{121}^z} = \frac{121 - T}{z}$$

Effects of Thermal Processing upon Food Components

The study of TDT curves for microorganisms suggests that many temperature/time combinations can be used to accomplish the required microbial destruction. However, it is necessary to know the effects of each combination on food nutrients and quality factors.

Harris and Karmas (1975) have reviewed the effects of heat processing in nutrients and have shown that many variables affect the rate of nutrient destruction. In a thermal process, if the retention of a specific nutrient is desired, its kinetics of degradation has to be studied in the food system and the dependence of the rate constant on temperature as well. There is a trend toward optimization of thermal processes for nutrient retention. This is accomplished primarily by the use of computers and prompted by the public concern with the nutrient content of processed foods. These optimum conditions are described through equations involving the time/temperature history of the product coupled with the parameters of reaction kinetics for destruction of nutrients and other factors.

In the field of chemistry, engineering and food science, values such as the reaction rate constant (k), the Arrhenius activation energy (E_a), decimal reduction time (D) and z value have been derived and used to establish and compare the reaction kinetics of several product components.

Kinetic data on food processing found in the literature usually refer to nutrient retention. A large number of researchers have dealt with thiamine losses during processing of vegetables. Farrer (1955) concluded that first order reaction kinetics were useful for prediction

of thiamine retention in both canning and storage of foods. In their classical work, Felliciotti and Esselen (1957) determined that the activation energy for the breakdown of thiamin in aqueous solution, phosphate buffered solutions and selected low-acid foods was in the range of 27 to 28.8 Kcal/mole.

The kinetics of destruction of several other food components have been studied, such as ascorbic acid (Kirk et al., 1977; Dennison and Kirk, 1978; Laing et al., 1978), peroxidase (Burnette and Flick, 1978), panthotenic acid (Hamm and Lund, 1978) and isozymes (Ling and Lund, 1978).

Hayakawa et al. (1977) extended these concepts to the destruction of sensory quality of vegetables. Green beans, corn and peas were subjected to various treatments to determine the reaction kinetic parameters for thermal destruction of organoleptic quality. Sensory evaluation for flavor was conducted in comparison to untreated samples. Organoleptic destruction curves were obtained by plotting the logarithm of isothermal heating time at which the quality of treated samples became objectionably poor against temperature. The z values were determined from these curves as 52 F° for green beans, 57 F° for corn and 51 F° for peas. These values are considerably greater than those for thermal inactivation of microorganisms. It was concluded that high temperatures can be used in processing for a safe product without seriously changing the food overall quality.

Quast and Da Silva (1977a) studied the temperature dependence of the cooking rate of dry legumes, including black beans. After water soaking at 22 °C for 12-16 hours, the beans were cooked at 98 °C, 116° C and 127 °C, until reaching "eating soft" texture as determined on a Kramer shear press. They considered a force of 2.5 lbf/g as

representative of an adequate cooking procedure. The plot of cooking time versus temperature produced a z value equal to 19 C°, indicating that the cooking time is decreased ten times for each increase of 19 °C in the processing temperature. This represents a benefit regarding energy savings during either commercial or home preparation of beans. The same authors (Quast and Da Silva, 1977b) reported that unsoaked beans presented slightly higher z values (21 C°).

OBJECTIVES

The literature search reveals that some extensive work has been done concerning legumes and their role in human nutrition. A great deal has been devoted to the influence of storage conditions upon cooking quality and the effect of cooking parameters upon nutritional quality of beans. Soaking in water and in various chemical solutions has been shown to shorten the cooking time for dry beans, including black beans. However, little effort has been made to quantify bean sensory quality as affected by those soaking and cooking procedures, or to evaluate the significance of instrumental data in relation to sensory scores for texture.

Kinetic concepts have been used to describe the thermal dependence of reactions involving many food components. Such an approach has seldom been used in regard to the bean softening process. The few data available seem to be highly affected by experimental conditions and such raw material parameters as bean species, variety, local of production, storage effects, etc.

This research was undertaken in order to provide more information concerning the phenomena involved in black bean cooking. The effect of some soaking regimes on shortening cooking time and quality maintenance was of primary interest, as well as the optimum processing parameters and the development of models to describe the relationship between sensory and instrumental measurement of texture. The study of the kinetic parameters involved in the cooking process as affected by

different soaking media was intended to provide a useful basis for extending the concepts to canning and home preparation of black beans.

EXPERIMENTAL

Soaking and Cooking Effects

A general scheme of the steps involved is presented in Fig. 3.

Raw Material

Black Turtle Soup Beans (Phaseolus vulgaris L.) were purchased locally from a Cuban market in Gainesville, FL, in 100-lb bags. The product was distributed by Country Foods, Div. of Agway, Inc., Syracuse, NY. Data on the origin and storage of the beans were not available. According to personal communication with the local supplier, they constituted a typical sample of the product. Their consumption is reasonably high in the area, primarily due to the presence of a growing Latin community. The beans were believed to represent a fresh lot in the market and presented a standard good quality for home and industrial preparation.

The raw material was analyzed for moisture, protein, total fat and ash contents, according to the procedures recommended by the AOAC (1975). The results are presented in Table IV.

The black beans were stored at 1.7° C in the original bag inside plastic containers until used. Prior to each experiment, a suitable portion of the beans was selected according to integrity and appearance, discarding extremes in size, odd-shaped, split, off-color beans or extraneous material.

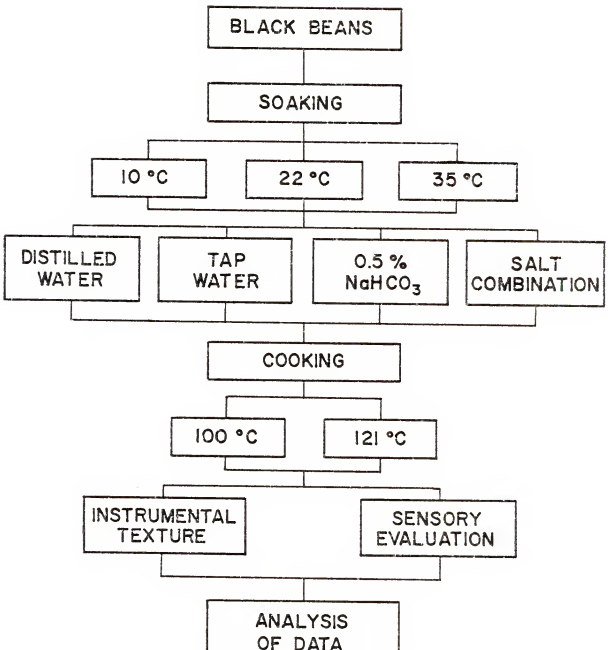


Fig. 3. General scheme of the study of soaking and cooking effects on black bean quality.

Table IV. Some physical and chemical characteristics of the black beans studied.

Parameter	Mean	Standard Deviation
Dimensions (cm)		
length	0.92	0.110
width	0.51	0.027
diameter	0.64	0.053
Weight (g)	0.216	0.048
Moisture (g/100 g)	14.05	0.20
Protein (g/100 g, N x 6.25)	21.22	0.61
Total fat (g/100 g)	1.04	0.18
Ash (g/100 g)	3.41	0.25

Soaking Procedures

A 3 x 4 factorial arrangement completely randomized with two replications was used. Four soaking media were studied: distilled water, tap water, 0.5% sodium bicarbonate solution and a combination of 2.5% sodium chloride, 1% sodium tripolyphosphate, 0.75% sodium bicarbonate and 0.25% sodium bicarbonate. This salt combination was developed by Rockland and Metzler (1967). Sodium tripolyphosphate was supplied by FMC Co., PA, and the other salts by Mallinkrodt, Inc., Paris, KY.

Each soaking regime was performed at 10 °C, 22 °C and 35 °C. A 100-g sample of selected black beans was added to 300 ml of each soaking medium. At pre-determined time intervals, the submerged beans were drained through a conic strainer for 2 minutes, blotted with a paper towel to remove the excess water and weighed. The pH of the strained solution was determined at the beginning and end of the soaking period. The increase in bean weight was assumed to be due to water absorption, and the data reported as water uptake per 100 g of black beans.

Cooking Regimes

After soaking, the total amount of soaked beans (100 g dry beans plus solution pick up) was drained, rinsed with cold tap water and put into no. 303 x 407 cans. A corresponding amount of unsoaked, dry black beans (100 g) was used as the control. When the samples were to be used for sensory evaluation, approximately 1 g of table salt was added to each can (approximately 0.22% w/w) before cooking, except for those that contained black beans soaked in the salt combination solution. This procedure was intended to compensate for the presence of sodium chloride in this solution which would interfere in the organoleptic comparisons.

Tap water at approximately 85 °C was added to each sample, leaving a 0.5 cm headspace. This represented the equivalent of 350 g water plus 100 g dry beans. The cans were sealed in an automatic can sealer equipped with steam injection in the headspace. The cans were processed in a vertical still retort at either 100 °C (open retort, as a water bath) or under 15 psi pressure at 121 °C. The cooking times varied with each experiment depending upon the specific purpose. The time periods were measured from retort temperature attainment to steam off. The retort come-up-time averaged 1 minute and its effect on cooking was not considered. The cooling process was performed in the retort when processing under pressure or in static tanks with running water when processing at 100 °C. The cooling phase lasted, in both cases, for approximately 5 minutes, until the cans reached 40 °C.

Instrumental Texture Measurements

The texture quality of the cooked black beans was evaluated by means of the puncture test developed by Bourne (1972), primarily due to the availability of the equipment and simplicity of the technique. Large quantities of beans were not required, so that a 208 x 006 (thermal death time - TDT) can provided sufficient material to serve as an experimental sample. The Instron Universal Testing Machine model TM (Instron Corporation, Canton, MA), equipped with CB and CCTM cells was used. During the measurements, several slight modifications were introduced in the method in order to speed the operation and adapt it to black bean analysis. As shown in Fig. 4, a flat faced steel probe (0.136 cm diameter) was fixed in the chuck located at the cross-head of the Instron, which moved up and down, at a velocity of 5.0 cm per

Fig. 4. Typical set-up of an Instron puncture test.

minute, guiding the probe to puncture the bean. The bean rested in a cylindric aluminum block (2.5 cm diameter) with a 0.5 cm diameter hole in the center. A countersink, prepared in the top of the block, held the bean during the test. In the lower portion of the block, a cone-shaped hole was drilled to avoid a build-up of material removed from the bean during puncture. The block was placed on the top of an inverted Instron compression load cell (CB, for forces up to 2,000 g and CCTM for forces over 2,000 g) for the test. Each time it was necessary to remove the block from the cell for clean-up, a new operation to center the hole in relation to the probe was needed, and this delayed the whole operation. To overcome this difficulty, a plastic slab (8 cm x 4 cm x 0.5 cm) was prepared, with a 2.5 cm hole, to accommodate the block. After centering the block on the top of the cell, at the beginning of the session of measurements, the plastic slab was fixed with adhesive tape to the cell. This set up provided automatic centering of the block hole after cleaning operations, thus preventing excessive delays. In one operation, an automatic extension cycle of 2 cm was used. The chart was moved manually, when the cross-head was moving upwards, after reaching the lowest limit. At the same time, the bean just measured was removed and replaced by another. This procedure did not interfere with the normal speed of operation, also providing an economy of paper, while registering only the essential maximum puncture force. By these procedures, a 10-bean sample could be evaluated in about 3 minutes.

In each determination, one can (no. 303 or thermal death time can) was considered an experimental unit. The response per can was obtained

as the average of several beans, the number being adjusted according to the variation observed during the analysis. When hard beans were measured, the fluctuation in the texture of individual beans was very high; therefore, a large number (usually 50) had to be tested to compensate for this variation. In the case of soft beans, less variation occurred, and the measurement of a minimum of 10 beans was satisfactory. The results were expressed as the average maximum force in grams (g) required to puncture one bean.

Sensory Evaluation

Multiple comparison tests, using a fully structured 9-point rating scale, were used to determine the color, texture, flavor and overall acceptability of the cooked black beans. The panel was composed entirely of 20 Brazilians, selected from those who consumed black beans regularly. Each session was performed with 10 of these selected panelists. All of them lived in married student housing complexes and were either students or student spouses. This made it difficult to conduct formal panels in an adequate sensory evaluation laboratory. To do this, it would have been necessary to oblige all panelists to travel from home to the lab within a limited period of time, in order to perform the sensory analysis. For this reason, the tests took place in a home setting. The samples were prepared in the pilot plant of the Food Science and Human Nutrition Department in such a way as to be ready by mid-afternoon, then immediately transported home and analyzed within 3 hours. According to the availability and convenience of each panelist, he/she attended the session which would run up to early evening. The atmosphere of testing was, therefore, that of a social event, where the sensory evaluation task

was performed as a part of the normal activities and not the main reason for the gathering. At any one time, the panelists received samples either from different soaking media but cooked under similar conditions of time and temperature, or from the same soaking solution but cooked at different times and a set temperature. Randomness was ensured by placing the samples in coded portion cups which were given in random order to each panelist. No flavorings were added at the time of testing and the samples were served at about 45 °C. All tests were performed in duplicate. A copy of the 9-point hedonic scale evaluation sheet is shown in Fig. 5.

Additional Experiments

Conditions for texture measurement. Two preliminary experiments were conducted in a randomized block design. One was intended to check the influence of the temperature of the beans (10 °C, 22 °C, 40 °C) during measurement of texture. The other tested the influence of elapsed time after processing (0, 4 days) on texture measurement. The samples were tested the same day of processing at the three temperature levels, and again after 4 days of storage, at room temperature only.

Influence of soaking time on texture of cooked black beans. A completely randomized design was used in experiments to establish the relationship between texture of cooked black beans, soaking time, water uptake and texture of soaked black beans. Several sets of 100-g samples of black beans were soaked in distilled water and in the salt combination solution at 22 °C. At selected time intervals, the soaking solutions were drained from some sets, the amount of water absorbed

NAME _____ DATE _____

PRODUCT Black Beans

You are receiving samples of black beans cooked at the same temperature and time. Please check them for color, texture, flavor and overall acceptability in the given order.

1. COLOR					
(9) Extremely poor	____	____	____	____	____
(8) Very poor	____	____	____	____	____
(7) Poor	____	____	____	____	____
(6) Slightly poor	____	____	____	____	____
(5) Fair	____	____	____	____	____
(4) Slightly good	____	____	____	____	____
(3) Good	____	____	____	____	____
(2) Very good	____	____	____	____	____
(1) Excellent	____	____	____	____	____
2. TEXTURE					
(9) Extremely tough	____	____	____	____	____
(8) Tough	____	____	____	____	____
(7) Moderately tough	____	____	____	____	____
(6) Slightly tough	____	____	____	____	____
(5) Eating soft	____	____	____	____	____
(4) Slightly soft	____	____	____	____	____
(3) Moderately soft	____	____	____	____	____
(2) Very soft	____	____	____	____	____
(1) Extremely soft	____	____	____	____	____
3. FLAVOR					
(9) Extremely poor	____	____	____	____	____
(8) Very poor	____	____	____	____	____
(7) Poor	____	____	____	____	____
(6) Slightly poor	____	____	____	____	____
(5) Fair	____	____	____	____	____
(4) Slightly good	____	____	____	____	____
(3) Good	____	____	____	____	____
(2) Very good	____	____	____	____	____
(1) Excellent	____	____	____	____	____
4. OVERALL ACCEPTABILITY					
(9) Extremely poor	____	____	____	____	____
(8) Very poor	____	____	____	____	____
(7) Poor	____	____	____	____	____
(6) Below fair	____	____	____	____	____
(5) Fair	____	____	____	____	____
(4) Above fair	____	____	____	____	____
(3) Good	____	____	____	____	____
(2) Very good	____	____	____	____	____
(1) Excellent	____	____	____	____	____

COMMENTS:

Fig. 5. Example of evaluation sheet used for sensory analysis (number in parentheses represent score assigned to each level).

determined by weighing and the texture of the soaked beans was determined by the puncture test. The drained and rinsed beans were then cooked in no. 303 cans for 60 minutes at 100 °C, and the texture of the cooked black beans evaluated using the Instron. All treatments were run in duplicate.

Kinetics of Black Bean Cooking

A general outline of the procedures is shown in Fig. 6.

Sample Preparation

Unsoaked black beans and black beans soaked for 12 hours at 22 °C in distilled water or the salt combination solution were used. Quantities equivalent to 5.0 ± 0.5 g dry weight of black beans were put into thermal death time (TDT) cans (208 x 006, American Can Company, Barrington, IL). Tap water at room temperature was added without leaving a headspace, and the cans were sealed. Special cans were also prepared to monitor the temperature and the time of processing. In these cans, copper-constantin 30-gage thermocouples approximately 5 cm long were passed through a hole drilled at the intersection of the body and the bottom of the TDT can. The thermocouples were held in place by means of a heat resistant epoxy cement. The junction inside the can was inserted to the center of one bean. In order to check for differences in heat penetration in different regions, the position of this control bean varied from run to run. Unsoaked beans required drilling a hole and fixation of the thermocouple with the epoxy cement; soaked black beans needed only manual pressure for insertion of the thermocouple. The outer extremity of the thermocouple was connected to another piece linked to a 4-point recorder (Speedomax H, Leeds

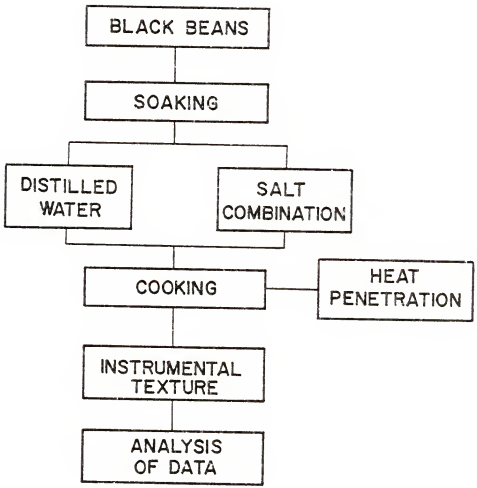


Fig. 6. General scheme of the kinetic studies on black beans cooking.

and Northrup Co., North Wales, PA) for registration of heat penetration and temperature control.

Processing Equipment

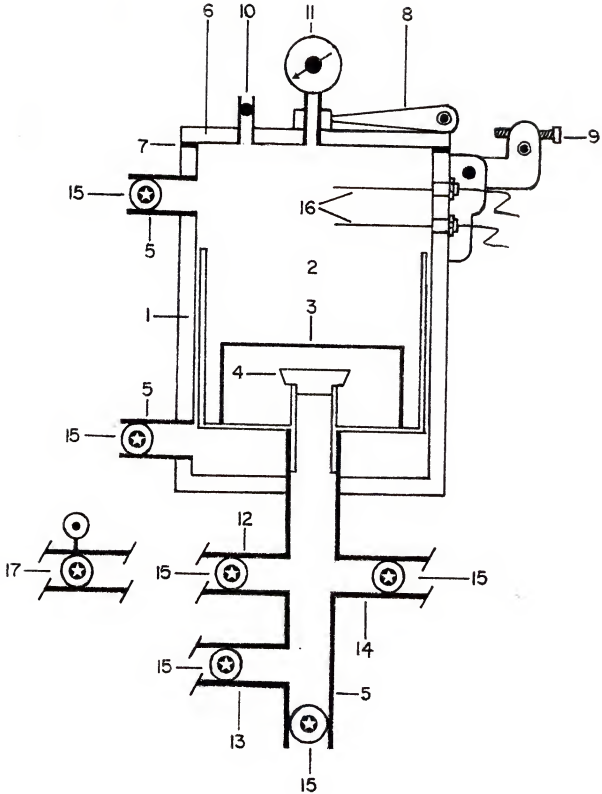
Processing at 100 °C and lower. A vertical still retort equipped with a temperature control system (Taylor Instrument Companies, Rochester, NY) was used as a water bath. The TDT cans were placed in the bath only after it reached constant processing temperature. The temperature was regulated by the control system, and controlled by both the thermometer in the retort and a thermocouple immersed in the heating medium and connected to the recorder. The cooling regime took place by rapidly immersing cans into a 10 °C water bath until the temperature reached 25 °C.

Processing at temperatures over 100 °C. A thermal death time retort, similar to that used by Schmidt et al. (1955) was used to process samples at temperatures over 100 °C. Its scheme is shown in Fig. 7. Essentially, it consists of a body (1), a chamber (2) with a sample support (3), adapter steam baffle (4), two side and one bottom drains (5). The cover (6) with rubber gasket (7) is secured and tightened by a holder (8) with a series of four screws (9). The cover also contains the bleeder (10) and the pressure gauge (11). Steam is supplied by two lines, one under controlled pressure (12) and the other directly from the 60-psi line (13). Cold water is also supplied to the retort through the inlet (14). Quick opening valves (15) are used for water and steam supplies and for drains. The retort body also contains two thermocouples (16) connected to the recorder and inserted

Fig. 7. Thermal death time retort schematic

1. Body (23 cm height x 14 cm diameter)
2. Chamber
3. Sample support
4. Adapter steam baffle
5. Drain
6. Cover
7. Rubber gasket
8. Holder
9. Screw
10. Bleeder
11. Pressure gauge
12. Controlled pressure steam line
13. 60-psi steam line
14. Cold water line
15. Quick-opening valve
16. Thermocouples
17. Pressure control valve

For operation details, see text.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through packing glands. One is connected to the small thermocouple wire that goes inside the can and the other gives retort temperature.

Before operating, the processing temperature is set by running the retort with only the pressure control valve (17) in operation, until a steady temperature is achieved. The bleeder, slightly open, helps in maintaining a constant temperature. During one run, the retort is loaded with the TDT cans, and the lid securely locked. Drain valves and bleeder are open in the beginning. Steam is quickly admitted simultaneously from both 60-psi and controlled pressure lines. The side drains are rapidly closed, then the bottom drain and finally the bleeder. This sequence provides adequate and fast venting. As the retort reaches processing temperature, the 60-psi line is closed, the temperature being maintained by the steam coming from the controlled pressure line (12) set to the desired temperature and by fine adjustment of the bleeder valve. This come-up-time is approximately 5 seconds and as short as physically possible. After reaching the desired processing time, monitored from the time the sample reached processing temperature, the steam valve is closed and cold tap water (22 °C) rapidly introduced into the retort chamber. At this time, the side drains are quickly open to ensure proper water circulation. The cooling phase lasts for less than 5 seconds, until the can temperature reaches 25 °C.

Processing Time

The time/temperature combinations used in the experiments are indicated in Table V. They represent the time the black beans were exposed to the processing temperature, recorded from the time the beans reached processing temperature, as registered by the thermocouple in

Table V. Processing temperatures and times for kinetic studies.

Soaking Medium	Temperature (°C)	Time (min)
Unsoaked	90	60 - 180 - 360 - 420 - 480 - 540 - 570 - 600
	100	30 - 60 - 90 - 100 - 120
	110	15 - 30 - 45 - 60 - 75
	121	5 - 15 - 25 - 35 - 45
	135	1 - 5 - 10 - 20 - 25 - 30
Distilled water	90	60 - 120 - 180 - 240 - 300 - 360 - 450
	100	10 - 20 - 30 - 45 - 60 - 75
	110	5 - 15 - 25 - 30 - 35
	121	1 - 2 - 3 - 4 - 5 - 10 - 12
	135	0.25 - 0.5 - 1 - 3 - 4 - 5
Salt combination	90	10 - 30 - 60 - 90 - 120
	100	2 - 5 - 10 - 15 - 20 - 25
	110	5 - 10 - 15 - 20 - 30
	121	0.1 - 0.25 - 0.5 - 1 - 2 - 3
	135	Unattainable (see text, p. 97)

the center of the control bean, to steam off (TDT retort) or when samples were withdrawn from the still retort.

Correction for Thermal Lag

The correction for the thermal lag was required to account for the accumulated effect of temperatures below the processing temperature during heating and cooling periods. This effect was calculated in relation to the processing temperature and represent an additional equivalent time of processing. During processing, a record of the temperature in the center of one bean in a can was obtained, and the heat penetration data were used to correct for the thermal lag. The equivalent processing time at each temperature and soaking condition and the z value were calculated according to an iterative procedure (Hayakawa et al., 1977), which involved the following steps:

1. A value for z was assumed and, with the data from heating and cooling curves, the equivalent processing time at the reference temperature for each heating and cooling period was calculated. This calculation was similar to that for the estimation of a mass sterilization value (Ball and Olson, 1957). The lethality at a single point, which was at the center of a bean, was estimated for temperatures below processing temperature by means of the formula:

$$L = \log^{-1} \frac{Ti - To}{z}$$

where: L = lethal rate

Ti = temperature at a given time (°C)

To = processing temperature (°C)

z = arbitrary z value (C°)

The lethality of each temperature Ti was calculated by multiplying its lethal rate by the time of exposure of the food, during heating and cooling. The sum of all lethalities was considered as the additional cooking time at the processing temperature and was added to the monitored processing time.

2. All times were plotted against the instrumental texture (g) at each temperature. The equation for the regression line obtained (Barr et al., 1979) was used to estimate the cooking time, for each temperature and soaking procedure, needed to reach a puncture force of 150 g. This value was obtained in the first part of the investigation, and was considered as an index for optimum texture of black beans. The corresponding times were assumed as analogous to a D value for microbial destruction and referred to as D_T (time in min to reach an instrumental texture mean value of 150 g penetration force).

3. The logs of the D_T values determined in the previous step were plotted against the corresponding temperatures. The slope of the regression line obtained was taken as -1/z. This can also be calculated by the equation

$$z = \frac{T_1 - T_2}{\log(D_{T2}/D_{T1})}$$

where D_{T1}, T_1 and D_{T2}, T_2 are two times and temperatures of processing that produce the same texture (150 g) of cooked black beans.

The z values obtained through these steps were compared to the assumed ones. The calculations were repeated until no significant difference was obtained between calculated and assumed z values. A typical example of this entire procedure is given in the Appendix. Although

conducted by hand calculations, all these steps can be performed by means of an adequate computer program (Hayakawa et al., 1977).

Estimation of the Reaction Rate Constants (k) and Activation Energy (E_a)

The reaction rate constants (k) were calculated based on the D_T values according to the relationship

$$k = \frac{2.303}{D_T}$$

The k values were expressed as min^{-1}.

The linear regression obtained in an Arrhenius plot (log k vs. 1/T) was used to calculate the activation energy (E_a) for each soaking condition by means of the following relationship:

$$\text{slope} = \frac{-E_a}{2.303 \times R}$$

where E_a is expressed in cal/mole, R—the gas constant—is equal to 1.987 cal/mole °K and temperatures are expressed in °K.

Comparison of Other Bean Samples

Three samples of other beans were used to check the applicability of the model obtained for black beans. These were as follows:

a. black beans (Phaseolus vulgaris L.) of the same origin as the ones used in the experiments, but stored at 37 °C for 5 months;

b. soybeans (Glycine max (L.) Merrill), variety Bragg, about 2 years old; and

c. pinto beans (Phaseolus vulgaris L.) purchased fresh (within 2 weeks of evaluation) at a local market.

Soaking was performed at 22 °C for 12 hours in either distilled water or the salt combination solution. The beans were packed in TDT cans

and submitted to the processing parameters established for the initial black bean sample. Beans soaked in distilled water were processed for 75 min at 100 °C and 10 min at 121 °C. Beans soaked in the salt combination solution were cooked for 25 min at 100 °C and 2 min at 121 °C.

Analysis of Data

Statistical analyses of the data collected in these experiments were performed using the Statistical Analysis System (SAS) as devised by Barr et al. (1979).

In the analysis of the sensory evaluation data, the General Linear Model (GLM) and Duncan's Multiple Range test (Duncan, 1955) were used. It was assumed that all panelists had the same perception and knowledge of the product under examination, so that the effect of the panelists was not included as a source of variation in the model.

Regression analyses were used in treating the data obtained in the kinetic of cooking study.

RESULTS AND DISCUSSION

Soaking and Cooking Effects

Soaking Procedures

The various soaking regimes were studied over a 24-hour period using the water uptake of 100-g black bean samples as a measure of soaking effectiveness. This phenomenon generally had two phases, as illustrated in Figs. 8, 9 and 10. Over 60% of the total water absorbed was picked up during the first two hours of soaking. The absorption rate decreased gradually after this time to a maximum water uptake around 95%, after which no further weight gain was observed (Table VI). The salt combination solution showed the slowest rate of water uptake, reaching the maximum only after 24 hours. All other media levelled off after 12 hours of soaking. However, no significant differences ($P < 0.716$) in maximum water uptake among distilled water, tap water, sodium bicarbonate and the salt combination solution were observed. The relatively high ionic strength of the multiple salt solution may retard the diffusion of water into the beans due to osmotic pressure and, consequently, slow down the rate of water uptake.

Soaking temperatures (10, 22 and 35 °C) also had no significant effect ($P < 0.130$) upon maximum water absorption, although a slightly higher total water uptake was observed at 35 °C (Fig. 10). These results are in general agreement with those of Quast and Da Silva (1977b), except that the maximum water uptake was relatively independent of temperature (all around 95% on an as-soaked basis) and below their results (120%). These authors, however, reported the

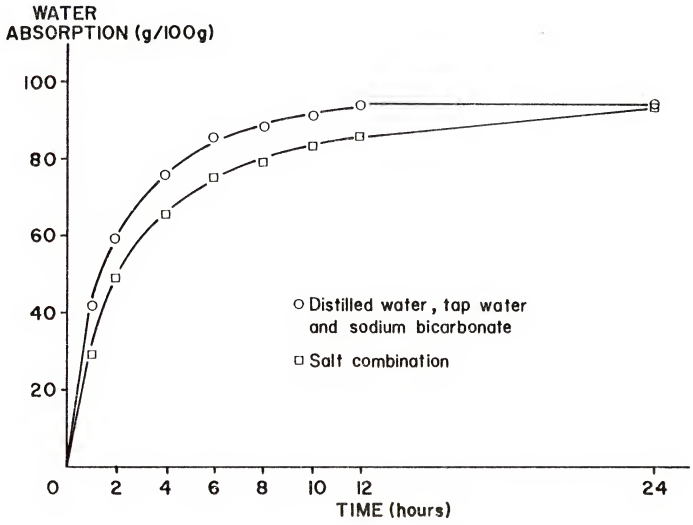

Fig. 8. Water absorption during soaking at 10 °C.

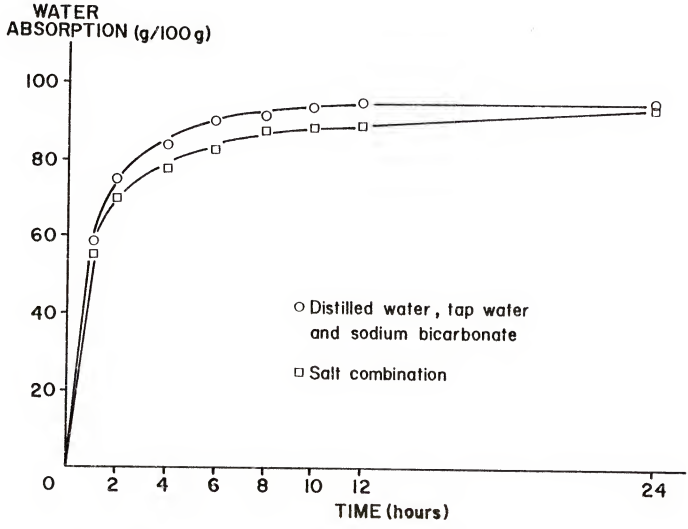

Fig. 9. Water absorption during soaking at 22 °C.

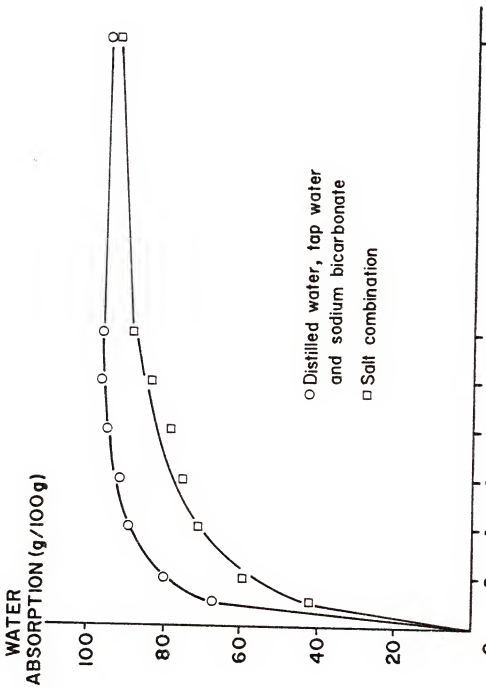

Fig. 10. Water absorption during soaking at 35 °C.

Table VI. Effect of soaking temperature on water absorption (weight gain, g/100 g dry beans) and pH changes in soaking solutions after 24 hours.

Soaking Medium	Temperature (°C)			pH	
	10	22	35	Initial	Final
Distilled water	95	96	97	5.9	5.7
Tap water	95	95	96	6.9	6.1
Sodium bicarbonate	95	95	95	8.4	7.3
Salt combination	94	94	94	8.9	7.5

Each value is the mean of two replicates.

data on a dry matter basis, thus including the initial dry bean moisture in the uptake values. Varriano-Marston and De Omana (1979) reported a maximum water uptake around 100% for black beans at room temperature in all solutions studied. Kon (1979) found that soaking at elevated temperature (up to 90 °C) increased the rate of water uptake in white beans. The small differences reported in these studies may be due to the different types and origins of the beans as well as storage and handling conditions. As evaluated by Muneta (1964), bean characteristics can vary appreciably according to the production location.

Considerable leaching of pigments was observed during soaking. The discarded soaking solution from the salt combination had a dark greenish color, in contrast to clear greenish in sodium bicarbonate and clear bluish in water.

In general, the pH of the soaking media decreased during the soaking period. The largest variation occurred in the salt combination solution, in which the pH decreased from 8.9 to 7.5, while a slight change (from 5.9 to 5.7) was observed on distilled water. The same trend was reported by Varriano-Marston and De Omana (1979). These authors attributed this pH decrease to the ionization of the cellular components, resulting in increased levels of hydrogen in the liquor. Some of these hydrogen ions were contributed by pectic acid. In basic soaking solutions, pH may also decrease as a consequence of spontaneous demethylation of pectic substances or increased activity of pectinmethylesterase. In addition, dissociation of hydrogen ions of the amino acid side chains also could contribute to the reduction in pH. The resulting charges on the macromolecules of the beans would influence water absorption.

Instrumental Texture Measurements

The puncture test developed by Bourne (1972) provided a simple and reliable method for texture evaluation. Fig. 11 depicts a comparison of typical curves obtained during the test of hard and soft beans. Partially cooked beans (A) usually produced one peak, while cooked beans (B) produced two peaks. This suggests that, on hard beans, the resistance to puncture is reflected by the sum of the effects of the skin plus the uncooked cotyledons. In soft beans the major resistance is given by the skin. The first peak would refer to the top skin; the second, smaller peak would correspond to the sum of resistance of the soft cotyledons plus the skin at the bottom of the bean.

Preliminary experiments were conducted to determine the influence of bean temperature upon puncture force and the effect of time elapsed after cooking upon this value. The results are summarized in Table VII. The statistical analysis (GLM) showed significant differences among reading temperatures ($P < 0.0001$), with the higher values associated with low temperatures (10 °C). No significant difference was observed in the averages of the measurements at 22 and 40 °C. Reading time did not show significant difference ($P < 0.1445$) between immediate measurements and those obtained 4 days later. Based on these findings, subsequent determinations of texture were performed at 22 °C, within 6 hours after cooking.

Cooking Quality

Based on the results shown in Figs. 8, 9 and 10, and due to the convenience of using overnight soaking, a standard soaking period of 12 hours at 22 °C was chosen for further experiments.

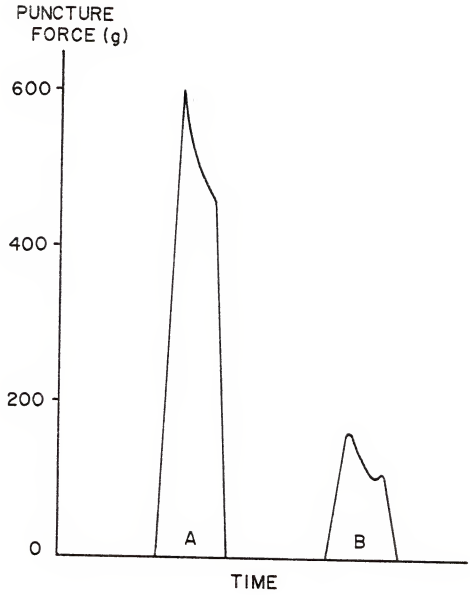

Fig. 11. Typical curves of the puncture tests for partially cooked (A) and cooked black beans (B).

Table VII. Influence of bean temperature and time delay on Instron measurements (puncture force, g) of soaked black beans cooked 60 min at 100 °C.

Soaking Medium	Soaking Temperature (°C)	Test Temperature (°C)	Time (day) 0	Time (day) 4
Distilled Water	10	10	229	
		22	184	186
		40	184	
	22	10	196	
		22	185	181
		40	186	
	35	10	235	
		22	167	190
		40	168	
Sodium Bicarbonate	10	10	133	
		22	142	152
		40	125	
	22	10	121	
		22	123	139
		40	119	
	35	10	141	
		22	127	140
		40	122	
Tap Water	10	10	223	
		22	185	177
		40	180	
	22	10	223	
		22	228	207
		40	197	
	35	10	231	
		22	181	227
		40	168	
Salt Combination	10	10	127	
		22	111	131
		40	99	
	22	10	112	
		22	116	130
		40	98	
	35	10	119	
		22	107	126
		40	110	

Each value is the mean of two replicates (10 to 50 beans per replicate).

In order to evaluate the relative influence of each soaking medium upon bean softening, after the 12-hour soaking, the black beans were cooked at 100 °C for 60 min and their texture measured instrumentally. The data in Table VIII show that soaking significantly enhances bean softening upon cooking ($P < 0.0001$). The most dramatic effect was caused by the salt combination solution; these samples required less than one-third the puncture force of unsoaked beans. This solution was rated the best, although not significantly different from the sodium bicarbonate solution, according to Duncan's test ($\alpha = 0.05$). Samples from distilled and tap water were also not significantly different.

Since the cooking of unsoaked beans involves an initial period of water absorption, it is expected that pre-soaking would lengthen the cooking exposure and promote more rapid bean softening. Also, the presence of sodium salts and high pH would increase the softening rate. Varriano-Marston and De Omana (1979) noted these facts while working with several soaking media containing sodium salts. They stated that the action of sodium salts in bean softening occurs by ion exchange and possibly chelation. Ions responsible for cellular firmness are replaced by sodium ions or leached out, resulting in solubilization of pectic substances during soaking and cooking. In addition, the disruption of hydrogen bonds upon heating speeds up bean softening. These authors observed that the amount of sodium in the soaking solution affected the mineral concentration in black beans. Potassium and magnesium were mostly lost by leaching in the presence of high salt concentrations. Rockland and Metzler (1967) justified the use of phosphates by their chelating effects, which aid in dissociating possible calcium or other metal salt-protein complexes.

Table VIII. Effect of soaking treatments on texture (puncture force, g) of black beans cooked 60 min at 100 °C.

Soaking Medium	Puncture Force (g)
Unsoaked beans	378[a]
Distilled water	196[b]
Tap water	199[b]
Sodium bicarbonate	138[c]
Salt combination	117[c]

Each value is the mean of two replicates. Means followed by the same letter are not significantly different by Duncan's test at $\alpha = 0.05$ level.

In subsequent experiments, unsoaked black beans and beans soaked in distilled water or in the salt combination solution were used. Tap water and sodium bicarbonate were not investigated further due to their observed similarities to distilled water and the salt combination solution, respectively. Distilled water was chosen over tap water to prevent any variability of soaking medium caused by possible difference in mineral composition or pH of tap water. The salt combination solution represented an interesting challenge due to its tested bean softening capacity and use in production of quick-cooking beans. When black beans soaked in the salt combination solution were cooked at 100 °C for different times, adequate eating texture (as monitored instrumentally and subjectively) was achieved after approximately 25 min of cooking. Under similar conditions, 60 min were necessary to cook black beans soaked in distilled water and unsoaked beans required 100 min to reach an eating-soft level (Table IX and Fig. 12). In an extended cooking regime, no detectable difference in texture was noticed between unsoaked beans and beans soaked in distilled water after 100 min of cooking, as indicated by Duncan's test. The same effects were observed when cooking was performed at 121 °C, as indicated in Table X and Fig. 13. Under these pressure conditions, 10 min at 121 °C was adequate to render a suitable product when the salt combination solution was used. Samples from unsoaked black beans and beans soaked in distilled water required 30 and 12 min, respectively. All soaking conditions showed no further changes in texture beyond 30 min of cooking. Highly significant ($P < 0.0001$) soaking and cooking interactions were found at both temperatures. This implies that the simple effects of each soaking solution upon bean

Table IX. Instrumental and sensory data for black beans cooked at 100 °C.

Measurement	Soaking Medium	Cooking Time (min)								
		20	40	60	80	100	120	240	360	480
Puncture Force (g)	Unsoaked	1432^{a}	489^{a}	263^{a}	158^{a}	137^{a}	126^{a}	115^{a}	92^{a}	92^{a}
	Dist. water	610^{b}	227^{b}	168^{b}	$131^{a,b}$	136^{a}	133^{b}	$103^{a,b}$	97^{a}	95^{a}
	Salt comb.	227^{c}	134^{c}	112^{c}	104^{b}	98^{b}	95^{c}	91^{b}	87^{b}	72^{b}
Color (1=Excellent, 9=Extremely poor)	Unsoaked	6.5^{a}	6.2^{a}	5.7^{a}	4.3^{a}	4.4^{a}	3.8^{a}	$3.1^{a,b}$	2.7^{a}	2.6^{a}
	Dist. Water	6.5^{a}	5.6^{a}	$5.0^{a,b}$	4.5^{a}	3.6^{a}	3.5^{a}	2.7^{b}	2.5^{a}	2.3^{a}
	Salt comb.	5.8^{a}	5.2^{a}	4.7^{b}	3.9^{a}	3.5^{a}	3.1^{a}	3.4^{a}	2.6^{a}	2.3^{a}
Texture (1=Extremely soft 9=Extremely tough)	Unsoaked	8.7^{a}	7.5^{a}	6.5^{a}	5.6^{a}	4.9^{a}	4.8^{a}	3.6^{a}	3.4^{a}	3.3^{a}
	Dist. water	8.2^{a}	6.7^{b}	5.9^{a}	$5.1^{a,b}$	4.9^{a}	4.0^{a}	3.7^{a}	3.5^{a}	3.3^{a}
	Salt comb.	6.4^{b}	4.5^{c}	4.2^{b}	3.9^{b}	3.7^{b}	3.6^{a}	3.4^{a}	3.4^{a}	3.3^{a}
Flavor (1=Excellent 9=Extremely poor)	Unsoaked	8.1^{a}	7.2^{a}	6.1^{a}	5.1^{a}	4.8^{a}	4.4^{a}	3.9^{a}	3.0^{a}	2.9^{a}
	Dist.water	7.7^{a}	6.3^{a}	$5.2^{a,b}$	5.0^{a}	4.3^{a}	4.1^{a}	3.0^{a}	2.9^{a}	2.6^{a}
	Salt comb.	6.3^{b}	4.4^{b}	4.2^{b}	3.5^{b}	3.9^{a}	3.2^{a}	2.9^{a}	2.7^{a}	2.3^{a}
Overall accept-ability (1=Excellent, 9=Extremely poor)	Unsoaked	8.1^{a}	7.2^{a}	6.0^{a}	5.2^{a}	4.7^{a}	5.0^{a}	3.5^{a}	2.9^{a}	2.7^{a}
	Dist. water	8.0^{a}	5.8^{b}	5.8^{a}	5.2^{a}	4.6^{a}	3.9^{a}	2.9^{a}	2.8^{a}	2.7^{a}
	Salt Comb.	6.0^{b}	4.8^{c}	4.4^{a}	3.3^{a}	3.9^{a}	2.8^{a}	3.3^{a}	2.6^{a}	2.2^{a}

Each value is the mean of two replicates. For each measurement and cooking time, means followed by the same letter are not significantly different by Duncan's test ($\alpha = 0.05$). Each sensory replicate consisted of the average score of 10 panelists.

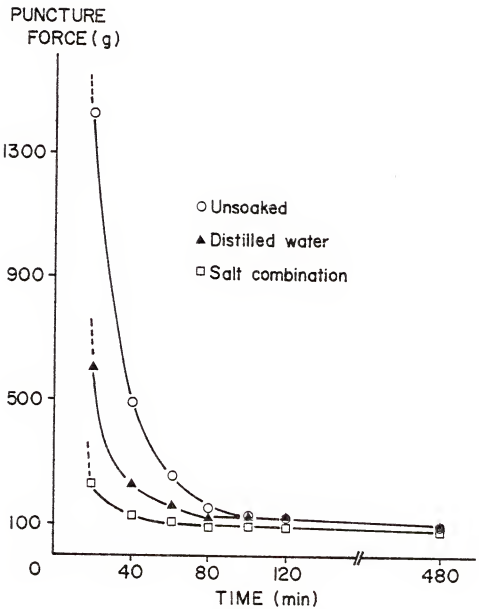

Fig. 12. Puncture force vs. cooking time at 100 °C for unsoaked beans and beans soaked 12 hours at 22 °C.

Table X. Instrumental and sensory data for black beans cooked at 121 °C.

Measurement	Soaking Medium	Cooking Time (min)			
		10	20	30	40
Puncture force (g)	Unsoaked	308[a]	127[a]	95[a]	91[a]
	Dist. Water	134[b]	98[b]	91[a]	90[a]
	Salt combination	108[b]	84[c]	87[a]	88[a]
Color (1=Excellent, 9=Extremely poor)	Unsoaked	4.9[a]	3.3[a]	4.1[a]	3.0[a]
	Dist. water	4.6[a]	3.6[a]	3.7[a,b]	3.6[a]
	Salt combination	3.9[b]	3.3[a]	3.3[b]	2.7[a]
Texture (1=Extremely soft 9=Extremely tough)	Unsoaked	6.9[a]	4.3[a]	4.3[a]	3.5[a]
	Dist. water	5.4[b]	3.8[a]	3.8[b]	3.0[a]
	Salt combination	4.5[c]	3.7[a]	3.3[c]	3.1[a]
Flavor (1=Excellent 9=Extremely poor)	Unsoaked	6.2[a]	4.4[a]	4.4[a]	4.0[a]
	Dist. water	5.3[a,b]	4.0[a,b]	3.7[a]	3.9[a]
	Salt combination	4.4[b]	3.4[b]	3.0[a]	3.0[a]
Overall acceptability (1=Excellent, 9=Extremely poor)	Unsoaked	6.3[a]	4.1[a]	4.2[a]	3.8[a]
	Dist. water	5.0[b]	3.9[a]	4.1[a]	3.6[a]
	Salt combination	4.3[c]	3.0[a]	3.0[b]	2.9[a]

Each value is the mean of two replicates. For each measurement and cooking time, means followed by the same letter are not significantly different by Duncan's test ($\alpha = 0.05$). Each sensory replicate consisted of the average score of 10 panelists.

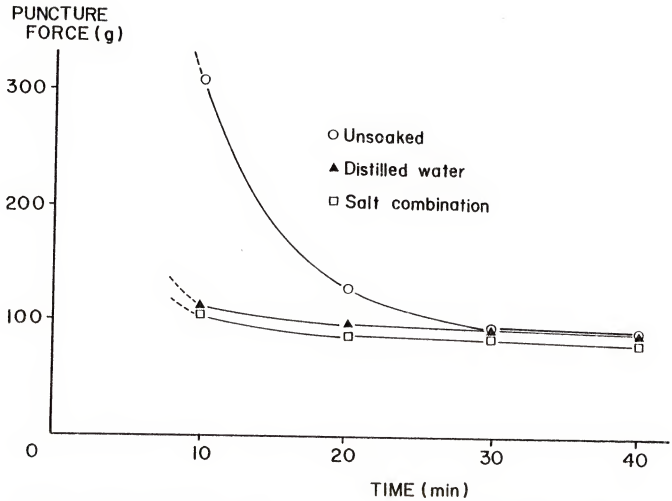

Fig. 13. Puncture force vs. cooking time at 121 °C for unsoaked beans and beans soaked 12 hours at 22 °C.

softening differ and the magnitude of any simple effect of the soaking treatments was dependent upon the cooking time. The best softening effects were shown by the salt combination solution (Figs. 12 and 13). These effects practically disappeared after cooking 80 min at 100 °C or 30 min at 121 °C.

At 100 °C, the cooking time was extended up to 8 hours in order to check the effect of overcooking on the quality of black beans. As indicated in Table IX, this extra time represented a 5-fold increase in time necessary to cook unsoaked black beans and about 16-fold over that required for beans soaked in the salt combination solution. Changes in texture and other quality parameters were not as dramatic as expected. This suggests that black beans can withstand overprocessing, provided enough water is available for complete rehydration and replacement of boil-off losses, otherwise scorching may occur. This fact is of particular importance in the case of processing that requires an extended cooking period to ensure a commercially sterile product. Thus, black bean overcooking is unlikely to be a quality limiting factor in food preparation and preservation, although such practices are energy wasteful.

To investigate the influence of soaking time on texture after soaking and cooking, black beans were soaked for different times and cooked at 100 °C for 60 min. As shown in Table XI, the salt combination solution produced a soft product after only 1-hour soaking. There was a rapid linear decrease in hardness up to 1-hour soaking. The texture became practically constant after this soaking period (Fig. 14B). On the other hand, black beans soaked in distilled water reached relatively

Table XI. Relationship of soaking time, water uptake, force on soaked, uncooked black beans and force on black beans cooked 60 min at 100 °C.

Soaking Medium	Soaking Time (h)	Water Uptake (g/100 g)	Puncture Force, Soaked, Uncooked (g)	Puncture Force, Cooked (g)
Distilled water	1	58	3564	231
	3	79	3375	228
	6	88	3250	225
	9	90	3137	215
	12	92	3039	185
	24	92	2729	188
Salt combination	1	43	3689	124
	3	67	3423	122
	6	77	3265	123
	9	83	3167	118
	12	84	3009	112
	24	93	3046	112

Each value is the mean of two replicates. Black beans soaked in the salt combination solution for less than one hour presented the following values for puncture force after cooking: 10 min, 272 g; 20 min, 240 g; 30 min, 223 g; 40 min, 178 g; 50 min, 155 g.

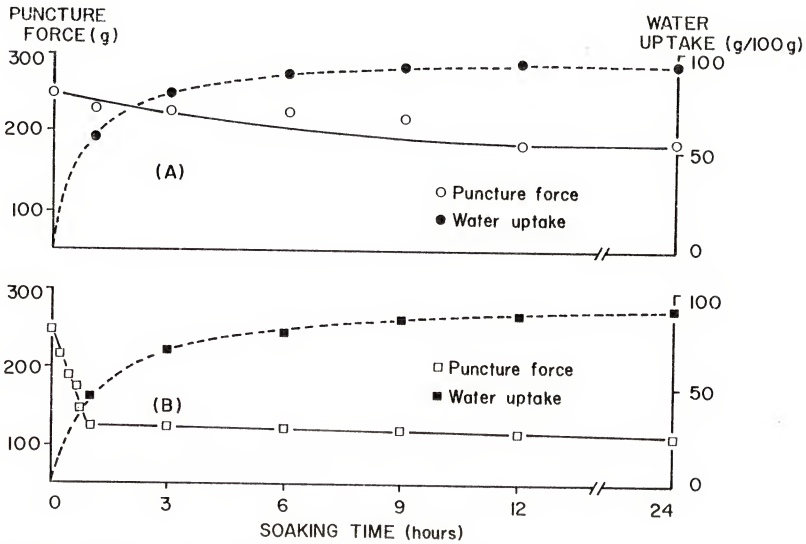

Fig. 14. Influence of soaking time on water absorption and texture of black beans after cooking 60 min at 100 °C (A - distilled water, B - salt combination solution).

uniform softness only after a 12-hour soaking period (Fig. 14A). These results agree with the conclusions of Quast and Da Silva (1977b) that the amount of hydration has little or no effect on the degree of cooking, after a minimum water uptake level has been reached. In the case of the salt combination solution, the rehydration level was only around 40 g per 100 g beans, with the remaining required water being picked up during the cooking period. Thus, the required water uptake for adequate bean softening depends upon soaking solution, immersion time and cooking regime.

It is, therefore, evident that the period of water uptake during cooking can be drastically reduced by pre-soaking. In addition, the presence of sodium salts in the soaking solution, combined with the chelating effect of phosphates, can dramatically reduce soaking and cooking times, even though only a little over 40% of the total 93% of water imbibed has been picked up during the first hour (Fig. 14B). This phenomenon is very helpful when large volumes of black beans have to be processed on short notice with the same efficiency as overnight soaking. Short soaking times also reduce the possibility of increase in microbial load that is likely to occur over long soaking periods (Hoff and Nelson, 1966).

One of the more positive quality features of pre-soaking observed throughout this investigation refers to the appearance and form of the cooked black beans in the container. An even distribution of beans and brine is accomplished when beans are soaked prior to cooking. When processing is performed in still retorts, heat penetration is favored by this distribution, due to the particle motion in a convection-heating mode. Conversely, unsoaked beans tend to stick together at the bottom

of the can due to swelling at the beginning of the cooking period. As observed in the processed product, large amounts of black beans remained as a block, increasing particle size and causing the heat penetration to occur primarily by conduction, which is slower than convection. In this case, irregular temperature distribution may be expected, resulting in more variation in the quality of the final product.

Sefa-Dedeh et al. (1978) reported a suitable model to predict puncture force of cooked cowpeas, based on soaking time, amount of water absorbed and puncture force of the soaked cowpeas before cooking. Based on the same approach, correlation and a stepwise regression procedure were used to develop a model for black beans. An analysis of the data (Tables XI and XII) showed that the puncture force of cooked black beans did not correlate well with any of the other parameters, namely soaking time ($r = -0.199$), water uptake ($r = 0.155$) and texture of soaked, uncooked black beans ($r = 0.044$). Further, the stepwise procedure did not consider texture of soaked, uncooked beans as significant at $\alpha = 0.05$ level in the model, the coefficient of determination being very low ($r^2 = 0.212$). For these reasons, it was concluded that the puncture force of cooked black beans cannot be confidently predicted based on soaking time, water absorbed, puncture force of soaked, uncooked beans or any interactions of these parameters.

Sensory Evaluation

Although instrumental analysis provides valuable insight into the black bean soaking and cooking phenomenon, the ultimate test for bean quality is sensory acceptability. A 9-point hedonic scale was used in multiple comparison to compare the relative effects of soaking

Table XII. Correlation coefficients (r) for data on Table XI.

	Soaking Time	Water Uptake	Puncture Force, Soaked Uncooked
Water uptake	0.703	---	
Puncture force, soaked uncooked	-0.843	-0.837	---
Puncture force, cooked	-0.199	0.155	0.044

and cooking treatments upon cooked black bean quality. For color, flavor and overall acceptability, the value 1 represented the most favorable rating (excellent) and 9 the least desirable score (extremely poor). In the case of texture, 1 corresponded to extremely soft beans and 9 to extremely tough beans. A score of 5 (eating-soft) indicated a general consensus of texture acceptability. It must be pointed out that setting a precise limit was extremely difficult, since texture preference varied among panelists. Yet, all agreed that 5 represented the upper limit at which black bean texture can be accepted for consumption.

The results of the sensory evaluation are presented in Tables IX and X. All quality parameters improved as cooking time increased. Adequate cooking of unsoaked black beans required over 80 min at 100 °C and approximately 20 min at 121 °C. Beans soaked in distilled water required a little less than 80 min at 100 °C and 10 min at 121 °C for proper cooking. Less than 40 min at 100 °C or 10 min at 121 °C were sufficient to cook beans soaked in the salt combination solution. These results agree with those previously discussed under cooking quality in regard to instrumental measurement of texture.

The statistical analysis (GLM) of the results at both cooking temperatures (Tables XIII, XIV, XI, XVI) revealed highly significant differences for all parameters for both the soaking and cooking regimes. As previously observed for puncture force, interactions of soaking and cooking were also highly significant for sensory texture ($P < 0.0001$ at 100 °C and $P < 0.0155$ at 121 °C) and instrumental texture ($P < 0.0001$ for both temperatures).

Table XIII. General Linear Model (GLM) for data on Table IX.

Source	d.f.	Color		Texture		Flavor		Overall Acceptability		Puncture Force	
		F	P<	F	P<	F	P<	F	P<	F	P<
Cooking time (C)	8	134.95	0.0001	162.28	0.0001	81.55	0.0001	46.84	0.0001	1124.54	0.0001
Soaking (S)	2	14.97	0.0001	105.82	0.0001	48.68	0.0001	26.33	0.0001	828.01	0.0001
C x S	16	2.02	0.0519	8.29	0.0001	2.22	0.0324	1.74	0.0986	325.73	0.0001
Error	27										
Error mean square		0.0841		0.0806		0.1742		0.3200		245.0741	

Table XIV. General Linear Model (GLM) for data on Table X.

	d.f.	Color		Texture		Flavor		Overall Acceptability		Puncture Force	
		F	P<	F	P<	F	P<	F	P<	F	P<
Cooking time (C)	3	25.21	0.0001	64.37	0.0001	12.02	0.0006	21.81	0.0001	256.81	0.0001
Soaking (S)	2	10.56	0.0023	26.40	0.0001	11.99	0.0014	20.15	0.0001	195.04	0.0001
C x S	6	2.29	0.1044	4.28	0.0155	0.35	0.8937	1.07	0.4311	109.83	0.0001
Error	12										
Error mean square		0.00800		0.0971		0.2979		0.1738		47.0833	

Table XV. Correlation coefficients (r) for cooking at 100 °C ($P < 0.0001$).

	Cooking Time	Color	Texture	Flavor	Overall Acceptability
Color	-0.823	---			
Texture	-0.684	0.909	---		
Flavor	-0.747	0.935	0.972	---	
Overall Acceptability	-0.748	0.935	0.959	0.974	---
Puncture Force	-0.381*	0.639	0.767	0.730	0.707

* Significant at $P < 0.0044$.

Table XVI. Correlation coefficients (r) for cooking at 121 °C ($P < 0.0001$).

	Cooking Time	Color	Texture	Flavor	Overall Acceptability
Color	-0.653	--			
Texture	-0.760	0.819	---		
Flavor	-0.596	0.837	0.823	---	
Overall Acceptability	-0.615	0.847	0.860	0.956	---
Puncture Force	-0.547	0.668	0.871	0.751	0.807

The considerable leaching of dark pigments into the soaking media was expected to influence unfavorably the sensory scores, but such did not occur. In general, the salt combination solution maintained the integrity of the cooked beans, while split grains were common in cooked, water-soaked beans and quite prevalent in cooked, unsoaked beans. The salt combination solution also imparted a dark black color to the beans, in contrast to dark brown in other soaking solutions. These facts contributed to the salt combination solution achieving the best sensory ratings of all treatments.

The overall acceptability of cooked black beans had the highest positive correlation with flavor at both temperatures ($r = 0.974$ at 100 °C and $r = 0.956$ at 121 °C). Sensory texture was the next, with $r = 0.959$ at 100 °C and $r = 0.860$ at 121 °C, followed by color ($r = 0.935$ at 100 °C and $r = 0.845$ at 121 °C). Low correlation coefficients were found between puncture force and cooking time, where high values were expected. As seen in Fig. 12 and 13, this seems to be caused by a non-linear relationship between these two parameters. The force decreased as cooking time increased until a certain softness level at which no remarkable change in texture occurred. This condition persisted even when the cooking time was extended far beyond that necessary for adequate cooking. Black beans, therefore, tolerate long cooking periods without undesirable softening.

As expected, puncture force showed the highest correlation with sensory texture ($r = 0.767$ at 100 °C and $r = 0.871$ at 121 °C). Based on this relationship, tentative mathematical models were developed to predict sensory responses based on instrumental data for texture. A log

model and the power function of Stevens (1960) were fitted to the data collected during all sensory and instrumental analysis (Fig. 15). The two resulting equations were as follows:

(1) Sensory texture = 2.30 ln (Force) - 6.63 ($r^2 = 0.87$)

(2) Sensory texture = 0.52 x (Force) $^{0.45}$ ($r^2 = 0.75$)

To check the predictability of the equations, black beans were cooked for various times at 100 °C to produce different degrees of softness and submitted to sensory and instrumental texture analyses. The results are presented in Table XVII. Both equations provided good estimates of texture. The power equation showed larger variations at high values, or hard beans, and the log equation presented more consistent results. However, either model may be used to predict the sensory texture score of black beans based upon the puncture force of a representative sample of beans.

On the practical side, it can be seen that it should not be necessary to carry out sensory panels over all experimentation steps. Once a reliable relationship is obtained between sensory and instrumental results, it would be necessary to obtain only the penetration force on a representative bean sample, the sensory value being extrapolated by calculations. The advantage becomes obvious when it is considered that sensory evaluation, though tremendously important and helpful in food research and development, is both a time and material consuming investigation. It also depends upon the capacity and availability of trained personnel and is subjected to more variability due to subjective and environmental factors (Amerine et al., 1965). In addition, mathematical relationships permit the investigator to vastly expand the range of experimentation and obtain data in less time with the same accuracy.

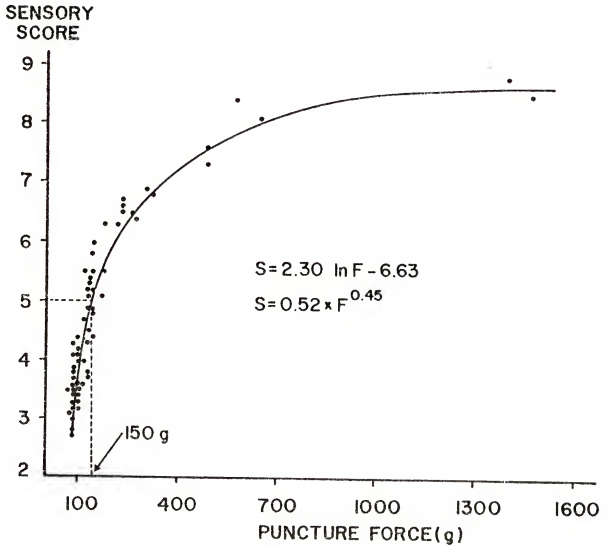

Fig. 15. Plot of sensory scores (S) vs. puncture force (F) of cooked black beans, showing the correspondence between a sensory score of 5 (eating soft) and 150 g puncture force.

Table XVII. Predicted and observed values for sensory texture based on puncture force, with relative per cent deviation from observed value.

Puncture Force (g)	Observed Sensory Score	Predicted Sensory Score			
		EQ. 1	% dev.	EQ. 2	% dev.
116	4.0	4.40	10.0	4.42	10.5
148	5.2	4.96	4.6	4.93	5.2
547	7.4	7.97	7.7	8.87	19.9

Each value is the mean of two replicates.

Considering both mathematical models as being adequate and a sensory score of 5 as the rating for acceptable texture of cooked black beans, the corresponding puncture force was calculated to be approximately 150 g (Fig. 15). This value represented an adequate degree of cooking for black beans. In other experiments, this value served as the reference to determine processing parameters for black beans. That is, these beans were considered adequately cooked from the standpoint of texture when they registered a 150 g puncture force by the instrumental measurement.

The analysis of commercial samples of canned black beans (Table XVIII) showed that these beans were softer than the limit value established in this research. The predicted sensory ratings were approximately 4.0, which corresponds to slightly soft cooked beans. These beans probably were cooked according to a standard processing treatment for similar beans, which is 20 min at 121 °C, after 12-hour soaking in water (Lopez, 1975). These values coincide with the results obtained in this study for water soaked black beans cooked under the same conditions, as seen in Table X.

Kinetics of Black Bean Cooking

Correction for Thermal Lags

As stated in the methodology, the times used for processing were not the actual time the samples were held at each temperature. Some cooking effect was also accomplished during the heating and cooling phases, at sub-processing temperatures. So, an equivalent processing time had to be added to account for the thermal lags. The correction for the lag needed to consider heat transfer within the can during

Table XVIII. Puncture force (g) and predicted sensory scores of commercial samples of canned black beans.

	Brand 1	Brand 2
Puncture Force (g)	97	101
Sensory score predicted		
- log equation	3.99	4.08
- power equation	4.07	4.15

Each value is the mean of two replicates.

processing. Since the product in this study consisted of dry or soaked individual beans immersed in a liquid, heat transfer would occur by both convection and conduction. The liquid provided the convective heat transfer, while conduction occurred during heat transfer to the interior of the beans. Also, the bean-to-bean contact caused by swelling during cooking, provided some conduction heat transfer from particle to particle. In the computation of the thermal lag effect, it is necessary to consider a transient heat temperature distribution in the can, estimated by means of experimentally derived equations, as stated by Ball and Olson (1957). The pseudo isothermal regions should also be considered in order to calculate the equivalent heating time at each temperature. In this study, however, it is also necessary to consider the nature of the beans and the shape of the TDT cans. These small cans present a conic elevation in the center, leaving a distance of approximately 0.5 cm from the top (Fig. 16). This particular shape is designed to avoid or minimize the temperature differential during heating which occurs in cylindrical cans. In other cylindrical containers, the cold spot is always along the central axis. In the TDT cans, the food material is accumulated in the internal periphery, so that the temperature gradient is much less. In addition, at most two black beans could occupy the same radius, and both would have about the same heat penetration characteristics. During this study, no differences in heat transfer were noticed among black beans placed in different positions inside the TDT cans, so that transient temperatures were not likely to have occurred or were negligible during the experiments. This is documented by the work of Hayakawa (1971) where, during the estimation of food temperatures in various processing and handling

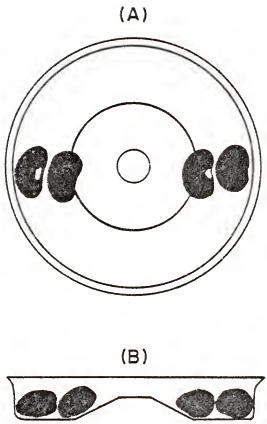

Fig. 16. Top (A) and cross section (B) views of a thermal death time can showing radial distribution of black beans.

treatments, no differences were noticed between experimental and computer calculated temperatures under a range of processing temperature treatments. Based on these assumptions, the calculation of thermal lags did not include transient temperature considerations. The equivalent processing time was variable for each treatment and had to be evaluated at each processing temperature. A typical example is given in the Appendix.

Temperature Dependence of the Softening of Black Beans

The estimation of the effects of a thermal process involving the heat penetration data for thermal lag correction needs two more parameters. These are analogous to D and z values which express the relative resistance of microorganisms to heat processing. The D value represents the isothermal heating time at a given temperature to reduce a microbial population by 90%. The slope of the thermal destruction curve is fundamental when considering microbial resistance. In the particular case of black beans, if texture is considered as the most important quality attribute, it would be meaningless to consider the destruction of 90% of the initial texture, or 90% loss in firmness, as a D value. This consideration will be discussed later to show that such a change in texture does not provide adequate cooking. Since the typical cooking curve did not present a constant slope, a point in the regression curve was picked to represent this optimum cooking stage. The time necessary to achieve this softness was designated D_T.

The plots of puncture force against cooking time (Figs. 17, 18 and 19) show that decrease in firmness occurred when cooking time was increased. The shape of the curves approximated that of a logarithmic function, suggesting a first-order kinetic reaction. When approaching the

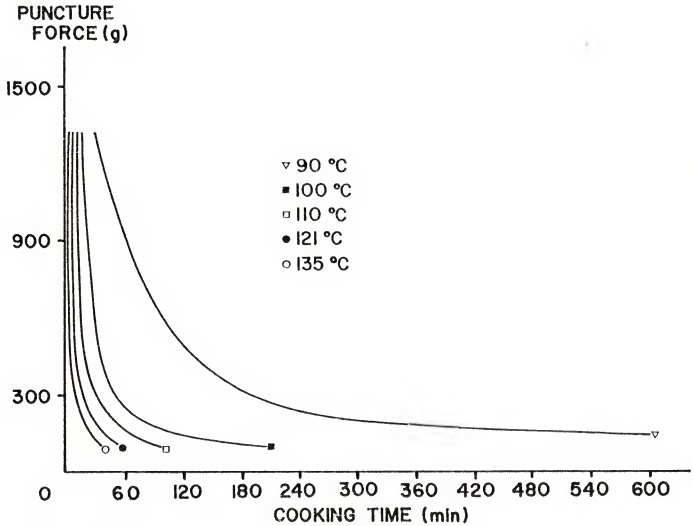

Fig. 17. Puncture force vs. cooking time for unsoaked black beans cooked at different temperatures.

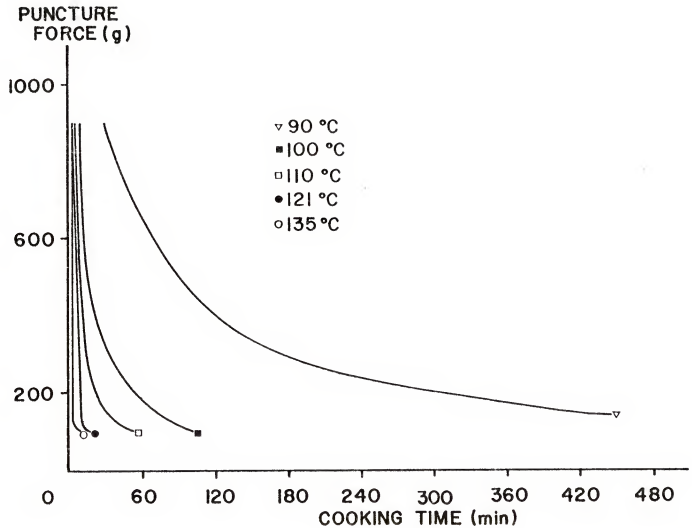

Fig. 18. Puncture force vs. cooking time for black beans, soaked in distilled water, and cooked at different temperatures.

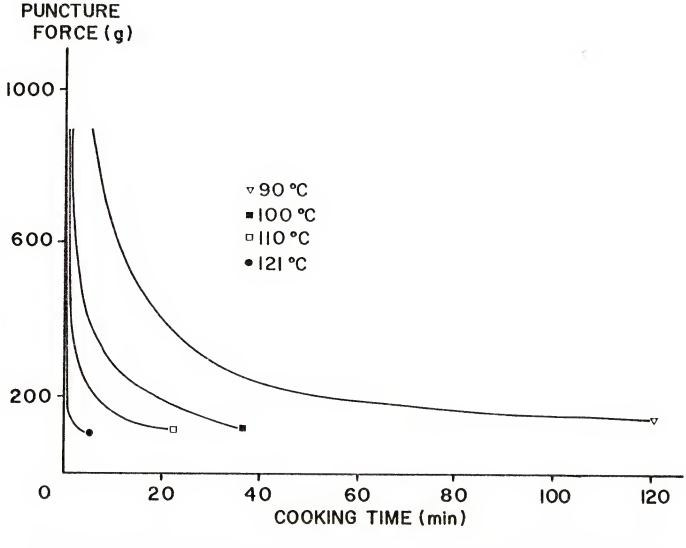

Fig. 19. Puncture force vs. cooking time for black beans, soaked in the salt combination solution and cooked at different temperatures.

optimum cooked stage (150 g puncture force), however, the line tends to become asymptotic to the x axis, changing to a zero-order reaction. Semi-log plots of each curve, as exemplified in Fig. 20, were not straight lines, showing that the log model would not fit the data. Therefore, the heat-induced softening reaction did not follow first-order kinetics. Higher correlation coefficients were obtained when a power model was used to fit the data, as shown in Table XIX. These findings disagree with those of Sefa-Dedeh et al. (1978), who found the rate of thermal softening of cowpeas to follow first-order kinetics. This difference is possibly due to the type of bean studied and instrumental technique of measurement. The texture values for cowpeas were usually over 20 kg force, in contrast to the values below 1,000 g for cooked black beans.

Several problems occurred with the collection of data at 135 °C. When unsoaked beans were processed at the short times used at this temperature (0.1 to 1.0 min), a texture differential could be noticed within the beans. The outer portion was soft but the center was still hard. This short processing time was inadequate for hydration at the bean center; consequently, cooking was prolonged although the center rapidly reached processing temperature. This caused some increase in the required processing time and some deviation from the softening trend. In the case of the salt combination solution, representative data could not be collected. When the cans reached 135 °C (zero time), a texture value below 150 g was already obtained. In the calculation for this treatment, the average TDT retort come-up-time (0.25 min) was considered as the time to cause the desired softening, D_T.

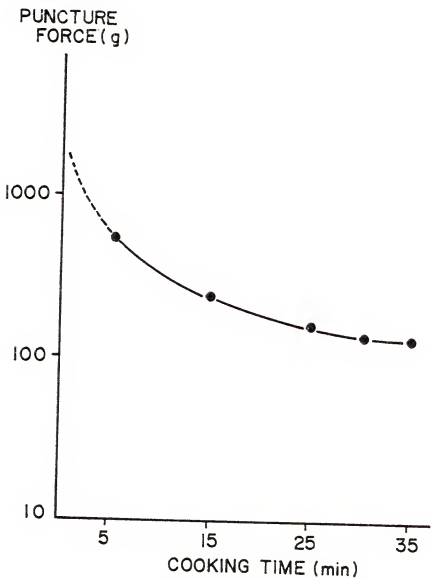

Fig. 20. Typical semi-log plot of puncture force vs. cooking time, showing non-linearity of the curve.

Determination of k and E_a Values

The application of the general rate expression of a reaction to the bean softening process may be given by the following equation:

$$\frac{dF}{dt} = -k\ F^n$$

where F is the observed puncture force, t is the cooking time and n is the order of the softening reaction. For the purposes of this study, the heating time required to reach a desired texture was compared to a D value for texture (D_T). It can be assumed that $1/D_T$ is an estimate of k, which would be better referred to as apparent rate constant for bean softening. So, the k values were calculated according to the relationship:

$$\text{Apparent rate constant (k)} = \frac{2.303}{D_T}$$

The values of D_T were determined by using the best fitting power equations for each soaking/temperature treatment, as the cooking time in min to reach 150 g puncture force (Table XIX).

The values of k and E_a are presented in Table XX and Figs. 21, 22 and 23. They depict the temperature dependence of the cooking rate. When soaking conditions are compared, the salt combination shows the most dramatic effects, water soaking is intermediate and unsoaked beans the least. Obviously, the same observation holds for the activation energy. Unsoaked beans had an E_a = 19,100 cal/mole, while water soaked beans reached E_a = 31,300 cal/mole and the salt combination solution was the highest, with E_a = 38,900 cal/mole. These results show that the mechanism of cooking was significantly affected by soaking regime.

Table XIX. Data for calculation of D_T and z values.

Soaking Medium	Temperature (°C)	Calculation of D_T*			Calculation of z**		
		Regression Equation*	r^2	D_T (min)	Regression Equation	r^2	z (C°)
Unsoaked	90	$F=23{,}496\ t^{-0.8001}$	0.96	553.72	$\log D_T=4.9933 - 0.0279\ T$	0.86	35.8
	100	$F=74{,}459\ t^{-1.346}$	0.96	100.66			
	110	$F=21{,}612\ t^{-1.210}$	0.97	60.81			
	121	$F=12{,}544\ t^{-1.241}$	0.99	35.40			
	135	$F=\ 2{,}485\ t^{-0.879}$	0.98	24.38			
Distilled Water	90	$F=12{,}481\ t^{-0.718}$	0.96	472.43	$\log D_T=6.614 - 0.0459\ T$	0.97	21.7
	100	$F=\ 7{,}016\ t^{-0.894}$	0.98	73.80			
	110	$F=\ 2{,}057\ t^{-0.781}$	0.98	28.58			
	121	$F=\ \ 779\ t^{-0.709}$	0.95	10.21			
	135	$F=\ \ 388\ t^{-0.781}$	0.80	3.38			
Salt Combination	90	$F=\ 2{,}485\ t^{-0.601}$	0.96	106.82	$\log D_T=7.250 - 0.057G\ T$	0.98	17.3
	100	$F=\ 1{,}304\ t^{-0.667}$	0.96	25.58			
	110	$F=\ \ 375\ t^{-0.366}$	0.77	12.19			
	121	$F=\ \ 278\ t^{-0.851}$	0.80	2.06			
	135	---	--	0.25			

*F = puncture force (g), t = cooking time (min) and D_T = cooking time to reach 150 puncture force

**T = cooking temperature in °C.

Table XX. Data for calculation of activation energy (E_a).

Soaking Medium	Temperature (°C)	$k(min^{-1})$	Regression Equation	r^2	E_a (cal/mole)
Unsoaked	90	0.00416	log k = 9.371 - 4,181.69 (1/T)	0.88	19,100
	100	0.0229			
	110	0.0378			
	121	0.0648			
	135	0.0946			
Distilled Water	90	0.00487	log k = 16.692 - 6,841.59 (1/T)	0.98	31,300
	100	0.0312			
	110	0.0806			
	121	0.226			
	135	0.681			
Salt Combination	90	0.0216	log k = 21.684 - 8,502.79 (1/T)	0.98	38,900
	100	0.09003			
	110	0.189			
	121	1.118			
	135	9.212			

In the regression equations, k = apparent rate constant, 2.303/D, min^{-1} and T = temperature, °K.

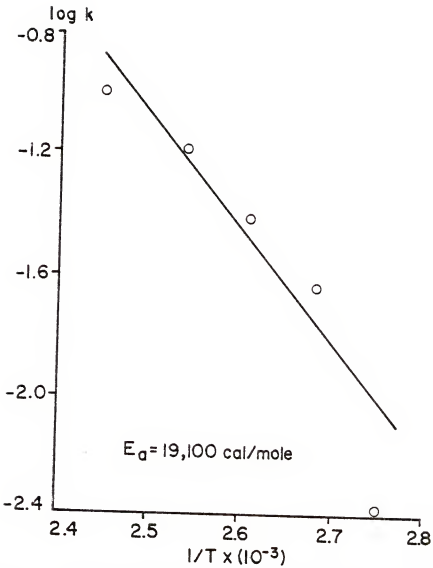

Fig. 21. Arrhenius plot for the softening activation energy of unsoaked black beans.

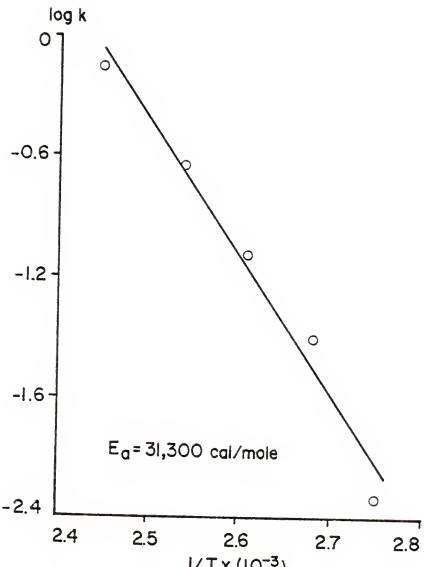

Fig. 22. Arrhenius plot for the softening activation energy of black beans soaked in distilled water.

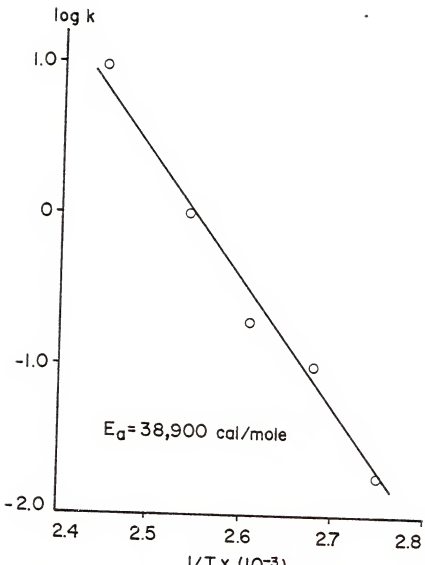

Fig. 23. Arrhenius plot for the softening activation energy of black beans soaked in the salt combination solution.

The reaction rate became more temperature dependent with soaking efficiency. These values are in the range of those reported for reactions in solution, i.e., from 10,000 to 30,000 cal/mole. The utility of the temperature dependence relationship is dependent upon the controlling reaction mechanisms. Considerable advantage may be taken of this significant increase in reaction rate that results with cooking temperature elevation when E_a is in the range of 10,000 to 30,000 cal/mole. Little advantage is gained by accelerated temperature studies if E_a is in the range of 2,000 to 3,000 cal/mole. For reactions with E_a values over 70,000 cal/mole, the rate of degradation may not be of any practical significance at the temperatures usually employed in food processing. Temperature response of the reaction rate is so high to preclude careful control in food systems (Lachman and DeLuca, 1970).

Determination and Interpretation of the z Values for Texture

When dealing with microorganisms, a z value represents the increase in temperature to shorten the destruction time by a factor of 10. In an analogous sense, the z concept can be applied to represent the increase in temperature required to produce a 10-fold time decrease to cause a desired effect. In the case of bean cooking, this effect would be the attainment of a texture measured as 150 g penetration force.

Initially, the z values for texture of cooked black beans were obtained considering D to be the time in min necessary to achieve 90% of texture destruction, based on the initial texture of uncooked beans. Only the initial slope of the cooking curves at each temperature was considered due to the tendency of the curve to flatten out once softening is reached (Figs. 17, 18 and 19). The z values were obtained in semi-log plots of the D values against the respective temperature, as seen

in Fig. 24. Unsoaked beans had the highest value, 39.5 C°, while water soaked beans resulted in z = 20 C° and the salt combination solution produced z = 16 C°. The uncooked beans were in the range of 3,000 g penetration force, thus a D value would correspond to approximately 300 g penetration force, far above the desired softness value. For this reason this approach could not be considered valid. It is important, however, when an intermediate stage of cooking is of interest, as occurs in the production of pre-cooked beans (Quast and Da Silva, 1977a).

The alternative was to consider the D values as those times required to produce a black bean texture corresponding to 150 g puncture force, which has been defined as D_T. The semi-log plots of D_T against temperature are shown in Figs. 25, 26 and 27. The regression lines presented a slope equal to -1/z, from which the z values were calculated. The Student's t test for comparing the slope of two regression lines (Steel and Torrie, 1960) showed that the slope of the regression for the unsoaked beans was different (α = 0.025) from the slope of the regression lines of the soaked beans. The same procedure showed no evidence of difference between the slopes of the regression lines for both soaking solutions. Nevertheless, unsoaked beans had the largest z value (36 C°), while soaked beans showed more temperature dependence, as demonstrated by z = 21 C° for water soaking and z = 17 C° for the salt combination solution. Therefore, soaked beans require less time for processing and an increase in processing temperature promotes more rapid softening than for unsoaked beans.

The z values encountered in this investigation differ sligthly from those reported by Quast and Da Silva (1977a, b). They reported a z = 19 C° for beans soaked in water, compared to z = 21 C° found here.

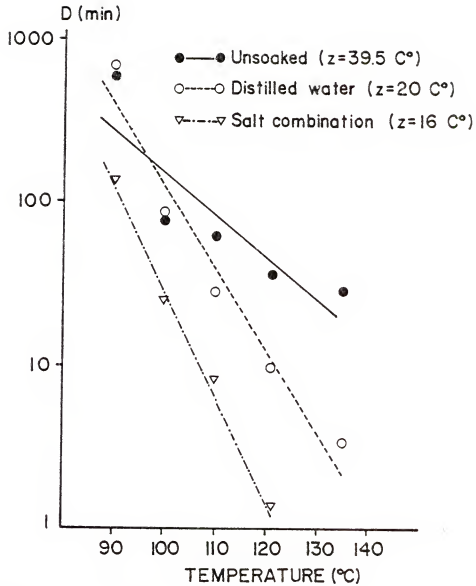

Fig. 24. Texture thermal destruction curve for determination of z values, considering D as the time for 90% destruction of initial texture.

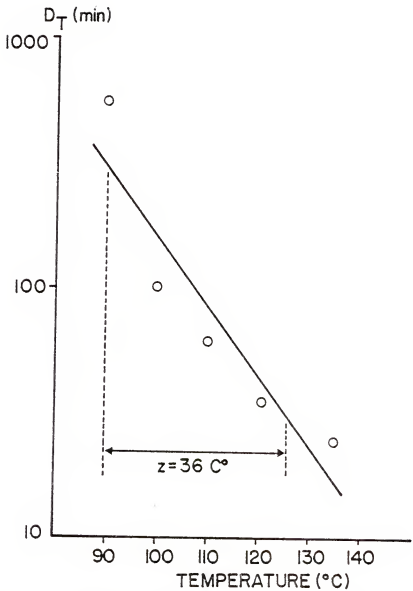

Fig. 25. Determination of z value for cooking of unsoaked black beans considering D as the time to achieve 150 g puncture force (D_T).

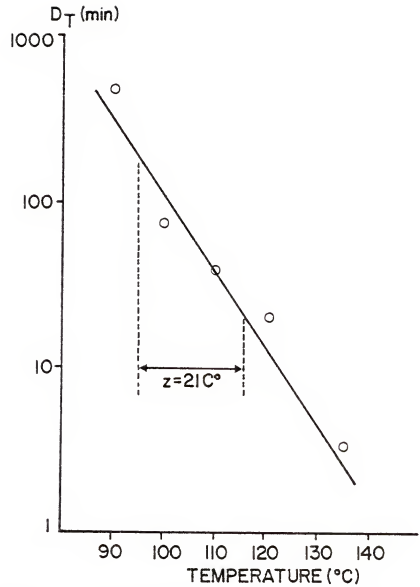

Fig. 26. Determination of z value for cooking of black beans soaked in distilled water considering D as the time to achieve 150 g puncture force (D_T).

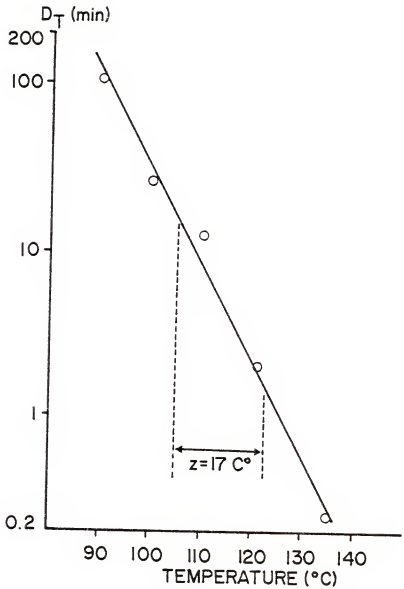

Fig. 27. Determination of z value for cooking of black beans soaked in the salt combination solution considering D as the time to achieve 150 g puncture force (D_T).

Such differences can be attributed to different methodology for cooking, texture measurements and black beans source.

The z values associated with bean cooking have some relevance concerning microbial safety. All of them are much greater than that of Clostridium botulinum (10 C°), which implies that microbial survival is more temperature dependent. By the same reasoning, a "commercially sterile" bean product does not necessarily mean an adequately cooked product. Commercial processes for similar food products have sterilizing values (Fo, equivalent time at 121 °C) around 6 min (Lund, 1975; Jackson and Shinn, 1979). Adequate cooking of unsoaked black beans at 121 °C would produce a Fo = 35.40 min, more than sufficient to assure a safe product. The Fo value would decrease to 10.21 min with water soaking. However, it would be as low as 2.06 min when the salt combination solution is used. Cooking at 110 °C produces Fo's below a safe value at all soaking conditions. Table XXI shows these Fo/temperature relationships. This raises two important considerations, concerning nutritional and microbiological aspects.

From the nutritional standpoint, reduction in cooking time can produce a more nutritive food, as reported in many investigations. It should be noted, however, that the relationships between inactivation of antinutritional factors and the soaking and cooking procedures reported here cannot be evaluated without further data. The literature search did not provide any data on the kinetics of thermal destruction of antimetabolites. The soaking of beans has been credited with the removal of toxic substances and also as helping the inactivation of trypsin inhibitor during cooking (Krishnamurthy, 1958; Bressani, 1973; Dutra de

Table XXI. Calculated Fo's achieved during cooking of black beans to reach 150 g puncture force, considering z = 10 C°.

Soaking Medium	Temperature (°C)	D_T (min)	Fo (min)
Unsoaked	90	553.72	0.44
	100	100.66	0.80
	110	60.81	4.83
	121	35.40	35.40
	135	24.38	612.40
Distilled water	90	472.43	0.38
	100	73.80	0.59
	110	28.58	2.27
	121	10.21	10.21
	135	3.38	84.90
Salt combination	90	106.82	0.08
	100	25.58	0.20
	110	12.19	0.97
	121	2.06	2.06
	135	0.25	6.28

Oliveira, 1973). Trypsin inhibitor was destroyed by treating soybean meal 20 min at 121 °C (Borchers et al., 1947a), while the same treatment inactivated hemagglutinin activity in black beans (Elias et al., 1979). It is probable that the survival of such factors are not of concern under the processing conditions used in this investigation.

On the other hand, cooking of soaked beans can produce, in some cases, low Fo's (Table XXI), mostly at low temperatures. This fact is not so important since low temperatures are used during home cooking of foods destined for immediate consumption. In this case, cooking and serving are done under aerobic conditions, which reduce the danger of botulism. Microbial hazards become a real concern in commercial operations, when pressure canning is used. At 121 °C, the danger becomes evident when the salt combination solution is used; a low Fo (2.06 min) could be achieved based on texture considerations. Additional processing time should be required to accomplish a desired lethality. This extended processing causes no harm to the product quality, since black beans can resist to long cooking, as verified in early stages of this study. At 135 °C, where the salt combination solution accomplishes a Fo = 6.28 min, there are some limitations to the process. The short time (0.25 seconds) is impractical and the beans so processed although having an acceptable texture, still lack cooked bean flavor, which would require some additional processing time to be developed.

Pre-soaking is a useful, if not essential, step in home cooking, especially in areas of high altitude. The boiling temperature of water decreases with increase in altitude and corresponding decrease in atmospheric pressure. The food processing time must be lengthened for

high altitudes. At 2,850 m (9,350 ft) altitude, water boils at approximately 90° C (Lorenz, 1975). Under these conditions, unsoaked black beans would require over 9 hours to cook. Water soaked beans could be adequately cooked in about 8 hours. Cooking time could be decreased to less than 2 hours if the salt combination solution is used. The economy in time would ultimately reflect in energy savings, of critical importance in bean consuming cultures. A rough estimate of cooking times at various altitudes and soaking procedures is presented in Table XXII.

The beneficial effects of soaking are even more applicable if pressure cooking is employed in home preparation. According to the data in Table XXIII, processing at 110 °C cuts the time to almost one-third that required at 100 °C, and to one-seventh at 121 °C, for water soaked beans. The salt combination solution enables reduction in cooking time to one-half at 110 °C and to less than one-tenth at 121 °C relative to 100 °C.

Comparison of Other Beans

The use of the recommended cooking times for black beans (Table XIX) did not produce consistent results when applied to other beans. As seen in Table XXIV, the storage-abused black beans (5 months at 37 °C) did not reach adequate texture upon water soaking and subsequent cooking 75 min at 100 °C or 10 min at 121 °C. They only approached satisfactory softness (172 g) when soaked in the salt combination solution and cooked 25 min at 100 °C. These results confirm those of Morris and Wood (1956) and Rockland and Metzler (1967) that high temperature storage induces the formation of hard cooking beans. None of the procedures used induced adequate soybean softening. The best result was achieved with water

Table XXII. Estimated cooking time for black beans as influenced by altitude and soaking regimes.

Location	Altitude (m)	Pressure (mmHg)	Water Boiling point (°C)	Approximate cooking time (min)		
				Unsoaked	Distilled Water	Salt Combination
Sea level	0	760	100	100	75	25
Brasilia, BRAZIL	938	684	97	190	115	40
Albuquerque, NM	1,527	633	95	220	180	60
Quito, ECUADOR	2,850	530	90	550	470	100
La Paz, BOLIVIA	3,900	470	87.5	720	680	160

Estimates based on TDT curves and regression equations. Location, altitude, pressure and boiling point of water adapted from the data of Lorenz (1975).

Table XXIII. Comparison of estimated cooking time (min) of black beans at different temperatures and soaking regimes.

Soaking Regime	Cooking Temperature (°C)		
	100	110	121
Unsoaked	100	60	35
Water	75	28	10
Salt combination	25	12	2

Table XXIV. Puncture force (g) of other bean types submitted to the recommended black bean process to achieve 150 g puncture force.

Soaking Medium	Temperature (°C)	Cooking Time (min)	Stored Black Beans	Soybeans	Pinto Beans
Distilled water	100	75	854	408	159
	121	10	508	195	166
Salt combination	100	25	172	407	173
	121	2	232	401	141

Each value represents the mean of five determinations.

soaking and cooking at 121 °C, although the texture was still over the 150 g limit. Quast and Da Silva (1977a) reported that water soaked soybeans required over 100 min at 100 °C and about 10 min at 121 °C for adequate cooking. So, the processing conditions in this experiment (75 min at 100 °C and 10 min at 121 °C) were not adequate to cook water soaked soybeans. Besides, the age of the soybeans used here (2 years at approximately 25 °C) might have influenced the softening process. Pinto beans behaved similarly to black beans, producing satisfactory texture under all conditions. These beans approached black beans in size and shape, and the sample studied was probably reasonably fresh in the market, so that short cooking times would be expected.

These results suggests that the application of cooking parameters for one type of bean to another can be done in some specific cases, but not in general. Each bean type presents its own cooking characteristics and, therefore, each type should be investigated individually. Bean species and varieties, production parameters and storage conditions must be more broadly considered in such studies.

SUMMARY AND CONCLUSIONS

Black Turtle Beans were soaked in several media and submitted to various cooking regimes. Cooked black beans were evaluated by both sensory and instrumental analysis to study the influence of soaking media upon product quality. Models for predicting sensory scores based upon instrumental data were developed. Kinetic studies were carried out to quantitize the nature of the phenomena involved in cooking of black beans. Results of these investigations show that:

1. No significant differences were present among the media in terms of maximum water uptake or soaking temperature.

2. Distilled and tap water presented similar effects upon bean softening upon cooking. A soaking solution containing several sodium salts presented the best softening effect, although not significantly different from sodium bicarbonate solution. This salt combination solution presented the slowest rate of water uptake among all media studied.

3. Black beans are quite resistant to oversoftening due to extended cooking.

4. Once a certain degree of water uptake is attained, additional hydration has little or no effect on the texture of cooked black beans.

5. The salt combination solution produced the most favorable scores in the sensory evaluation of color, texture, flavor and overall acceptability.

6. High correlation coefficients were found between sensory and instrumental texture. Logarithmic and power models can be used to describe this relationship and to predict reasonably well sensory scores based on physical data.

7. The temperature dependence of the cooking rate, expressed in terms of energy of activation, showed the salt combination solution as the highest (E_a = 38,900 cal/mole) as compared to water soaked (E_a = 31,300 cal/mole) and unsoaked black beans (E_a = 19,100 cal/mole).

8. The z values also showed higher temperature dependence of the cooking rate when the salt combination solution was used. A z = 17 C° was estimated for this solution, while water soaked black beans presented z = 21 C° and unsoaked black beans z = 36 C°.

9. All z values are greater than those reported for dangerous microorganisms. Some processing, however, would require time in excess of that needed for bean softening in order to achieve adequate Fo's for microbiological safety.

10. Reduction in cooking time by pre-soaking of black beans is very important for energy savings, particularly for those areas of high altitude. A good alternative would be the use of pressure cooking combined with pre-soaking.

11. The determination of adequate dry bean processing conditions must involve considerations of bean variety, age, production parameters and storage conditions.

12. Further research is necessary to establish kinetic parameters for destruction of antinutritional factors and for flavor development in black beans. In addition, the study of the variation in kinetic

parameters for black bean cooking as influenced by storage conditions is of great interest. The possibility of producing quick-cooking black beans by using the salt combination solution should be explored. This solution consists of industrial chemicals readily available at reasonable prices. However, their availability in some parts of the world may make the solution use impractical. In such situations, the study of any possible indigenous chemicals or plant materials that possess similar ion exchange and chelating properties for bean softening should be encouraged.

APPENDIX

EXAMPLE OF THE ITERATIVE PROCEDURE FOR CORRECTION OF THERMAL LAG

Step 1

A. Consider black beans soaked in distilled water and assume $z = 12\ C°$.

B. Estimate the equivalent processing time at each temperature accomplished during heating and cooling phases, using the data obtained from the recorder chart. This equivalent processing time is to be added to the monitored processing time. A typical example of this procedure is as follows, using the data for cooking at 121 °C.

   a. Extract from the recorder chart the change in temperature in the center of the control bean during heating and cooling phases.

   b. Prepare a table containing heating and cooling times, temperature at each time, time differential, lethal rate and lethality. Lethal rate is determined by the equation:

$$LR = \log^{-1} \frac{Ti - 121}{12}$$

where Ti is the temperature at a given time, 121 is the processing temperature and 12 is the assumed z value. Lethality is determined by multiplying the lethal rate by the time differential.

c. The sum of all lethalities is the equivalent process time for the specific processing temperature. Table XXV shows these data.

C. Add the equivalent processing time (0.63 min) to the monitored processing time at 121 °C. Determine the D_T values (time in min to reach 150 g puncture force) by means of regression analysis. The results are presented in Table XXVI.

D. Estimate z value by fitting a linear regression with log D_T against the respective temperature. The slope of the line is equal to -1/z. In this example, the equation was as follows:

$$\log D_T = 6.64 - 0.046\ T \quad (r^2 = 0.97)$$

and: slope = -1/z

$$-0.046 = -1/z \qquad z = 21.8\ C°$$

E. Check the z value obtained (21.8 C°) against the assumed value (z = 12 C°). In this case, the difference was too big, so go to step 2.

Step 2

A. Consider a z value close to that obtained in step 1, such as z =21 C°.

B. Perform the same operations (B though E) of step 1. Compare the newly z value with the assumed one. The data obtained are presented on Table XXVII.

Table XXV. Data for correction of thermal lag during processing of water soaked black beans at 121 °C.

Phase	Time (min)	Temperature (°C)	Δt* (min)	Lethal Rate	Lethality (min)
Heating	0	25	0.05	$1x10^{-8}$	$5x10^{-10}$
	0.05	75	0.07	$1.4x10^{-4}$	$1x10^{-5}$
	0.12	100	0.11	0.02	$1.9x10^{-3}$
	0.23	110	0.23	0.12	0.03
	0.46	115	0.12	0.32	0.04
	0.58	117	0.12	0.46	0.06
	0.70	118	0.12	0.56	0.07
	0.82	119	0.35	0.68	0.24
	1.17	120	0.11	0.83	0.09
	1.28	120.5	0.12	0.91	0.11
	1.40	121	--	--	--
Cooling	0.07	75	0.07	$1.4x10^{-4}$	$1x10^{-5}$
	0.17	50	0.10	$1.2x10^{-6}$	$1.2x10^{-7}$
	0.70	25	0.53	$1x10^{-8}$	$5.3x10^{-9}$
Equivalent time (min)					0.63

* Δt = time differential.

Table XXVI. Data for calculation of D_T values, considering the correction for thermal lag and z = 12 C°.

Temperature (°C)	Equivalent Processing Time (min)	Regression Equation*	r^2	D_T** (min)
90	0.59	$F = 12{,}419\ t^{-0.718}$	0.96	469.15
100	0.76	$F = 6{,}788\ t^{-0.887}$	0.98	73.56
110	0.20	$F = 2{,}032\ t^{-0.777}$	0.98	28.63
121	0.63	$F = 724\ t^{-0.682}$	0.98	10.06
135	0.39	$F = 359\ t^{-0.741}$	0.81	3.25

* F = puncture force (g) and t = cooking time (min).

** D_T = cooking time (min) to achieve 150 g puncture force.

Table XXVII. Data for calculation of D_T values, considering the correction for thermal lag and z = 21 C°.

Temperature (°C)	Equivalent Processing Time (min)	Regression Equation *	r^2	D_T** (min)
90	0.75	$F = 12{,}481\ t^{-0.718}$	0.96	472.43
100	0.97	$F = 7{,}016\ t^{-0.894}$	0.98	73.80
110	0.25	$F = 2{,}057\ t^{-0.781}$	0.98	28.58
121	0.80	$F = 779\ t^{-0.709}$	0.95	10.21
135	0.49	$F = 388\ t^{-0.781}$	0.80	3.38

* F = puncture force (g) and t = cooking time (min).

** D_T = cooking time (min) to achieve 150 g puncture force.

C. The linear regression obtained using log D_T against temperature is as follows:

$$\log D_T = 6.61 - 0.046\ T \quad (r^2 = 0.97)$$

D. The z value is estimated as 21.7 C°.

E. Since a small difference is obtained, the z value is assumed to be 21 C°.

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BIOGRAPHICAL SKETCH

Carlos Alberto Bento da Silva was born January 3, 1944, in Castelo, State of Espirito Santo, Brazil. He entered the Escola Nacional de Agronomia of the former Universidade Rural do Brasil, now Universidade Federal Rural do Rio de Janeiro (UFRRJ), in March, 1963. He received a degree of Engenheiro Agronomo in December, 1966. In March, 1967, he started working at that University as an Auxiliar Professor. In August, 1971, he entered the graduate program in Food Technology at the Faculdade de Tecnologia de Alimentos, Campinas, Sao Paulo, Brazil, where he received a Master of Science degree in October, 1972. Upon returning to the UFRRJ he was promoted to Assistant Professor in the Departamento de Tecnologia de Alimentos. In March, 1976, he was awarded a scholarship from UFRRJ/PEAS/MEC/Brazil to pursue a Ph.D. degree at the University of Florida. He expects to receive his Ph.D. degree with a major in Horticultural Sciences (Food Science and Human Nutrition) in December, 1979.

He is married to Aricleusa C. B. da Silva and they have two daughters, Consuelo and Carla.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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